ECOLOGY AND ENVIRONMENT: BIOL 124 AT HAWAII COMMUNITY COLLEGE



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Ecology and Environment:

A textbook for BIOL 124 at Hawaii Community College

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TABLE OF CONTENTS

Licensing

1: Environmental Science

- Page 1.1: The Earth, Humans, and the Environment
- Page 1.2: The Process of Science
- Page 1.3: Environment and Sustainability
- Page 1.4: Environmental Ethics
- Page 1.5: Environmental Justice and Indigenous Struggles
- Page 1.S: Environmental Science (Summary)

2: The Physical World

3: Matter, Energy, and Life

- Page 3.1: Matter
- Page 3.2: Energy
- Page 3.3: A Cell is the Smallest Unit of Life
- Page 3.4: Energy Enters Ecosystems Through Photosynthesis
- Page 3.5: Energy Flow through Ecosystems
- Page 3.6: Biogeochemical Cycles
- Page 3.S: Matter, Energy, and Life (Summary)

4: Biomes and the Biosphere

- Page 4.1: Terrestrial Biomes
- Page 4.2: Aquatic Biomes
- Page 4.3: Chapter Resources

5: Community and Population Ecology

- Page 5.1: Population Demographics and Dynamics
- Page 5.2: Population Growth and Regulation
- Page 5.3: The Human Population
- Page 5.4: Community Ecology
- Page 5.5: Chapter Resources

6: Conventional and Sustainable Energy

- Page 6.1: Challenges and Impacts of Energy Use
- Page 6.2: Non-Renewable Energy Sources
- Page 6.3: Renewable Energy Sources
- Page 6.4: Chapter Resources

7: Conservation and Biodiversity

- Page 7.1: Introduction to Biodiversity
- Page 7.2: Origin of Biodiversity
- Page 7.3: Importance of Biodiversity

- Page 7.4: Threats to Biodiversity
- Page 7.5: Preserving Biodiversity
- Page 7.6: Chapter Resources

8: Environmental Hazards and Human Health

- Page 8.1: The Impacts of Environmental Conditions
- Page 8.2: Environmental Health
- Page 8.3: Environmental Toxicology
- Page 8.4: Bioremediation
- Page 8.5: Case Study - The Love Canal Disaster
- Page 8.S: Environmental Hazards and Human Health (Summary)

9: Water Availability and Use

- Page 9.1: Water Cycle and Fresh Water Supply
- Page 9.2: Water Supply Problems and Solutions
- Page 9.3: Water Pollution
- Page 9.4: Water Treatment
- Page 9.5: Case Study - The Aral Sea - Going, Going, Gone
- Page 9.6: Chapter Resources

10: Food and Hunger

- Page 10.1: Food Security
- Page 10.2: Biotechnology and Genetic Engineering
- Page 10.3: Chapter Resources

11: Conventional and Sustainable Agriculture

- Page 11.1: Soil Profiles and Processes
- Page 11.2: Soil-Plant Interactions
- Page 11.3: Conventional Agriculture
- Page 11.4: Pests and Pesticides
- Page 11.5: Sustainable Agriculture
- Page 11.S: Conventional and Sustainable Agriculture (Summary)

12: Environmental Effects of Forestry

13: Air Pollution, Climate Change, and Ozone Depletion

- Page 13.1: Atmospheric Pollution
- Page 13.2: Ozone Depletion
- Page 13.3: Acid Rain
- Page 13.4: Climate Change
- Page 13.5: Chapter Resources

14: Sustainability - Ethics, Culture, and History

- Page 14.1: The Human Dimensions of Sustainability- History, Culture, Ethics
- Page 14.2: It's Not Easy Being Green- Anti-Environmental Discourse, Behavior, and Ideology
- Page 14.3: The Industrialization of Nature- A Modern History (1500 to the present)
- Page 14.4: Case Study- Agriculture and the Global Bee Colony Collapse

- Page 14.5: Sustainability Ethics

Index

Glossary

Glossary

Detailed Licensing

Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

CHAPTER OVERVIEW

1: Environmental Science

Learning Outcomes

After studying this chapter, you should be able to:

- Describe what the environment is, and some of its major components.
- Identify the shared characteristics of the natural sciences
- Understand the process of scientific inquiry
- Compare inductive reasoning with deductive reasoning
- Describe the goals of basic science and applied science
- Define environmental science
- Understand why it is important to study environmental science
- Explain the concept of sustainability and its social, political, and cultural challenges
- Evaluate the main points of environmental ethics
- Describe the concept of environmental justice
- Differentiate between developed and developing countries

Page 1.1: The Earth, Humans, and the Environment

Page 1.2: The Process of Science

Page 1.3: Environment and Sustainability

Page 1.4: Environmental Ethics

Page 1.5: Environmental Justice and Indigenous Struggles

Page 1.S: Environmental Science (Summary)

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Page 1.1: The Earth, Humans, and the Environment

What is Environmental Science?

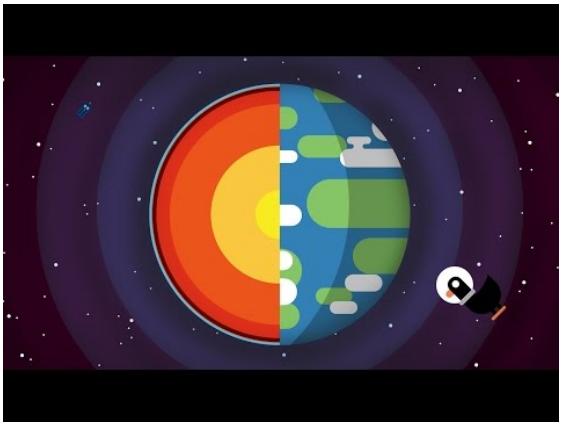
Environmental science is the dynamic, interdisciplinary study of the interaction of living and non-living parts of the environment, with special focus on the impact of humans on the environment. The study of environmental science includes circumstances, objects, or conditions by which an organism or community is surrounded and the complex ways in which they interact.

Why Study Environmental Science?

The need for equitable, ethical, and sustainable use of Earth's resources by a global population that nears the carrying capacity of the planet requires us not only to understand how human behaviors affect the environment, but also the scientific principles that govern interactions between the living and non-living. Our future depends on our ability to understand and evaluate evidence-based arguments about the environmental consequences of human actions and technologies, and to make informed decisions based on those arguments.

From global climate change to habitat loss driven by human population growth and development, Earth is becoming a different planet—right before our eyes. The global scale and rate of environmental change are beyond anything in recorded human history. Our challenge is to acquire an improved understanding of Earth's complex environmental systems; systems characterized by interactions within and among their natural and human components that link local to global and short-term to long-term phenomena, and individual behavior to collective action. The complexity of environmental challenges demands that we all participate in finding and implementing solutions leading to long-term environmental sustainability.

Perspectives: A brief history of planet Earth:



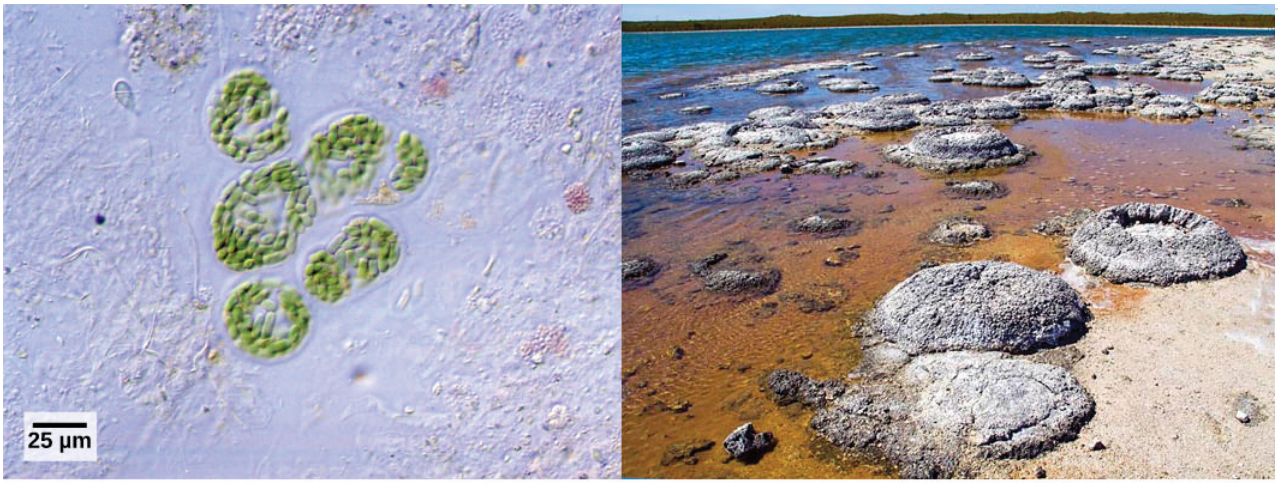
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Page 1.2: The Process of Science



(a) (b)

Figure $Page1.2.1$. (a) The cyanobacteria seen through a light microscope are some of Earth's oldest life forms. These (b) stromatolites along the shores of Lake Thetis in Western Australia are ancient structures formed by the layering of cyanobacteria in shallow waters. (Credit a: modification of work by NASA; scale-bar data from Matt Russell; credit b: modification of work by Ruth Ellison)

Like other natural sciences, environmental science is a science that gathers knowledge about the natural world. The methods of science include careful observation, record keeping, logical and mathematical reasoning, experimentation, and submitting conclusions to the scrutiny of others. Science also requires considerable imagination and creativity; a well-designed experiment is commonly described as elegant or beautiful. Science has considerable practical implications and some science is dedicated to practical applications, such as the prevention of disease (figure 2). Other science proceeds largely motivated by curiosity. Whatever its goal, there is no doubt that science has transformed human existence and will continue to do so.

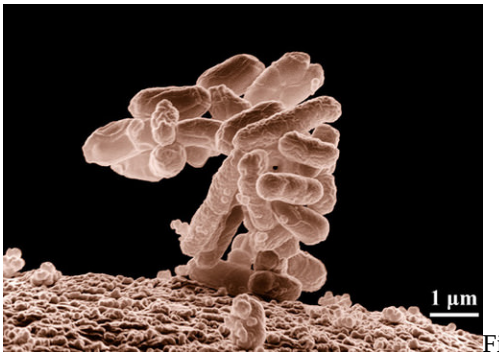


Figure $Page1.2.2$. Biologists may choose to study Escherichia coli (E. coli), a bacterium that is a normal resident of our digestive tracts but which is also sometimes responsible for disease outbreaks. In this micrograph, the bacterium is visualized using a scanning electron microscope and digital colorization. (credit: Eric Erbe; digital colorization by Christopher Pooley, USDA-ARS)

The Nature of Science

Biology is a science, but what exactly is science? What does the study of biology share with other scientific disciplines? **Science** (from the Latin *scientia*, meaning "knowledge") can be defined as a process of gaining knowledge about the natural world.

Science is a very specific way of learning about the world. The history of the past 500 years demonstrates that science is a very powerful way of gaining knowledge about the world; it is largely responsible for the technological revolutions that have taken place during this time. There are areas of knowledge, however, that the methods of science cannot be applied to. These include such things as morality, aesthetics, or spirituality. Science cannot investigate these areas because they are outside the realm of material phenomena, the phenomena of matter and energy, and cannot be observed and measured.

The **scientific method** is a method of research with defined steps that include experiments and careful observation. The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses. A **hypothesis** is an proposed explanatory statement, for a given natural phenomenon, that can be tested. Hypotheses, or tentative explanations, are different than a **scientific theory**. A scientific theory is a widely-accepted, thoroughly tested and confirmed explanation for a set of observations or phenomena. Scientific theory is the foundation of scientific knowledge. In addition, in many scientific disciplines (less so in biology) there are **scientific laws**, often expressed in mathematical formulas, which describe how elements of nature will behave under certain specific conditions, but they do not offer explanations for why they occur.

Natural Sciences

What would you expect to see in a museum of natural sciences? Frogs? Plants? Dinosaur skeletons? Exhibits about how the brain functions? A planetarium? Gems and minerals? Or maybe all of the above? Science includes such diverse fields as astronomy, computer sciences, psychology,biology, and mathematics. However, those fields of science related to the physical world and its phenomena and processes are considered **natural sciences** and include the disciplines of physics, geology, biology, and chemistry. Environmental science is a cross-disciplinary natural science because it relies of the disciplines of chemistry, biology, and geology.

Scientific Inquiry

One thing is common to all forms of science: an ultimate goal to know. Curiosity and inquiry are the driving forces for the development of science. Scientists seek to understand the world and the way it operates. Two methods of logical thinking are used: inductive reasoning and deductive reasoning.

Inductive reasoning is a form of logical thinking that uses related observations to arrive at a general conclusion. This type of reasoning is common in descriptive science. A life scientist such as a biologist makes observations and records them. These data can be qualitative (descriptive) or quantitative (consisting of numbers), and the raw data can be supplemented with drawings, pictures, photos, or videos. From many observations, the scientist can infer conclusions (inductions) based on evidence. Inductive reasoning involves formulating generalizations inferred from careful observation and the analysis of a large amount of data. Brain studies often work this way. Many brains are observed while people are doing a task. The part of the brain that lights up, indicating activity, is then demonstrated to be the part controlling the response to that task.

Deductive reasoning or deduction is the type of logic used in hypothesis-based science. In deductive reasoning, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical thinking that uses a general principle or law to forecast specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid as long as the general principles are valid. For example, a prediction would be that if the climate is becoming warmer in a region, the distribution of plants and animals should change. Comparisons have been made between distributions in the past and the present, and the many changes that have been found are consistent with a warming climate. Finding the change in distribution is evidence that the climate change conclusion is a valid one.

Both types of logical thinking are related to the two main pathways of scientific study: descriptive science and hypothesis-based science. **Descriptive** (or discovery) **science** aims to observe, explore, and discover, while **hypothesis-based science** begins with a specific question or problem and a potential answer or solution that can be tested. The boundary between these two forms of study is often blurred, because most scientific endeavors combine both approaches. Observations lead to questions, questions lead to forming a hypothesis as a possible answer to those questions, and then the hypothesis is tested. Thus, descriptive science and hypothesis-based science are in continuous dialogue.

> ***"Scientists have become the bearers of the torch of discovery in our quest for knowledge."*** *– Stephen Hawking and Leonard Mlodinov, in The Grand Design (2010), Bantam Books*

Hypothesis Testing

Biologists study the living world by posing questions about it and seeking science-based responses. This approach is common to other sciences as well and is often referred to as the scientific method. The scientific method was used even in ancient times, but it was first documented by England's Sir Francis Bacon (1561–1626) who set up inductive methods for scientific inquiry. The scientific method is not exclusively used by biologists but can be applied to almost anything as a logical problem-solving method.



Figure $Page1.2.3$. Sir Francis Bacon is credited with being the first to document the scientific method.

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. One Monday morning, a student arrives at class and quickly discovers that the classroom is too warm. That is an observation that also describes a problem: the classroom is too warm. The student then asks a question: "Why is the classroom so warm?"

Recall that a hypothesis is a suggested explanation that can be tested. To solve a problem, several hypotheses may be proposed. For example, one hypothesis might be, "The classroom is warm because no one turned on the air conditioning." But there could be other responses to the question, and therefore other hypotheses may be proposed. A second hypothesis might be, "The classroom is warm because there is a power failure, and so the air conditioning doesn't work."

Once a hypothesis has been selected, a prediction may be made. A prediction is similar to a hypothesis but it typically has the format "If . . . then . . . ." For example, the prediction for the first hypothesis might be, "*If* the student turns on the air conditioning, *then* the classroom will no longer be too warm."

A hypothesis must be testable to ensure that it is valid. For example, a hypothesis that depends on what a bear thinks is not testable, because it can never be known what a bear thinks. It should also be **falsifiable**, meaning that it can be disproven by experimental results. An example of an unfalsifiable hypothesis is "Botticelli's *Birth of Venus* is beautiful." There is no experiment that might show this statement to be false. To test a hypothesis, a researcher will conduct one or more experiments designed to eliminate one or more of the hypotheses. This is important. A hypothesis can be disproven, or eliminated, but it can never be proven. Science does not deal in proofs like mathematics. If an experiment fails to disprove a hypothesis, then we find support for that explanation,

but this is not to say that down the road a better explanation will not be found, or a more carefully designed experiment will be found to falsify the hypothesis.

Each experiment will have one or more variables and one or more controls. **Experimental variables** are any part of the experiment that can vary or change during the experiment. **Controlled variables** are parts of the experiment that do not change. Lastly, experiments might have a **control group**: a group of test subjects that are as similar as possible to all other test subjects, with the exception that they don't receive the experimental treatment (those that do receive it are known as the **experimental group**). For example, in a study testing a weight-loss drug, the control group would be test subjects that don't receive the drug (but they might receive a placebo, such as sugar pill, instead). Look for these various things in the example that follows:

An experiment might be conducted to test the hypothesis that phosphate (a nutrient) promotes the growth of algae in freshwater ponds. A series of artificial ponds are filled with water and half of them are treated by adding phosphate each week, while the other half are treated by adding a non-nutritional mineral that is not used by algae. The experimental variable here is presence/absence of a nutrient (phosphate). One potential controlled variable would be the volume of water in each tank. The amount of water that algae have access to may influence the results, thus researchers want to *control* its influence on the results by making sure all test subjects get the same amount. The control group consists of the tanks that received a placebo (non-nutritional mineral) instead of the phosphate. If the ponds with phosphate show more algal growth, then we have found support for the hypothesis. If they do not, then we reject our hypothesis. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid (Figure $Page1.2.3$). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

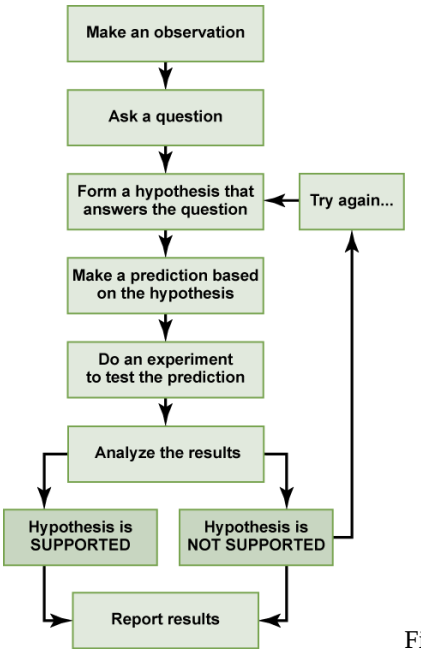


Figure $Page1.2.4$. The scientific method is a series of defined steps that include experiments and careful observation. If a hypothesis is not supported by data, a new hypothesis can be proposed.

In the example below, the scientific method is used to solve an everyday problem. Which part in the example below is the hypothesis? Which is the prediction? Based on the results of the experiment, is the hypothesis supported? If it is not supported, propose some alternative hypotheses.

1. My toaster doesn't toast my bread.
2. Why doesn't my toaster work?
3. There is something wrong with the electrical outlet.
4. If something is wrong with the outlet, my coffeemaker also won't work when plugged into it.
5. I plug my coffeemaker into the outlet.
6. My coffeemaker works.

In practice, the scientific method is not as rigid and structured as it might at first appear. Sometimes an experiment leads to conclusions that favor a change in approach; often, an experiment brings entirely new scientific questions to the puzzle. Many times, science does not operate in a linear fashion; instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests.

Basic and Applied Science

Is it valuable to pursue science for the sake of simply gaining knowledge, or does scientific knowledge only have worth if we can apply it to solving a specific problem or bettering our lives? This question focuses on the differences between two types of science: basic science and applied science.

Basic science or "pure" science seeks to expand knowledge regardless of the short-term application of that knowledge. It is not focused on developing a product or a service of immediate public or commercial value. The immediate goal of basic science is knowledge for knowledge's sake, though this does not mean that in the end it may not result in an application.

In contrast, **applied science** aims to use science to solve real-world problems, such as improving crop yield, find a cure for a particular disease, or save animals threatened by a natural disaster. In applied science, the problem is usually defined for the researcher.

Some individuals may perceive applied science as "useful" and basic science as "useless." A question these people might pose to a scientist advocating knowledge acquisition would be, "What for?" A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead to find solutions to actual problems. Both approaches are valid. It is true that there are problems that demand immediate attention; however, few solutions would be found without the help of the knowledge generated through basic science.

One example of how basic and applied science can work together to solve practical problems occurred after the discovery of DNA structure led to an understanding of the molecular mechanisms governing DNA replication. Strands of DNA, unique in every human, are found in our cells, where they provide the instructions necessary for life. During DNA replication, new copies of DNA are made, shortly before a cell divides to form new cells. Understanding the mechanisms of DNA replication (through basic science) enabled scientists to develop laboratory techniques that are now used to identify genetic diseases, pinpoint individuals who were at a crime scene, and determine paternity (all examples of applied science). Without basic science, it is unlikely that applied science would exist.

Another example of the link between basic and applied research is the Human Genome Project, a study in which each human chromosome was analyzed and mapped to determine the precise sequence of the DNA code and the exact location of each gene. (The gene is the basic unit of heredity; an individual's complete collection of genes is his or her genome.) Other organisms have also been studied as part of this project to gain a better understanding of human chromosomes. The Human Genome Project (Figure $Page1.2.5$) relied on basic research carried out with non-human organisms and, later, with the human genome. An important end goal eventually became using the data for applied research seeking cures for genetic diseases.

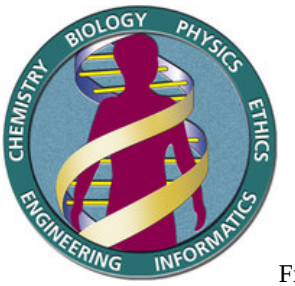


Figure $Page1.2.5$. The Human Genome Project was a 13-year collaborative effort among researchers working in several different fields of science. The project was completed in 2003. (credit: the U.S. Department of Energy Genome Programs)

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Scientific Work is Transparent & Open to Critique

Whether scientific research is basic science or applied science, scientists must share their findings for other researchers to expand and build upon their discoveries. For this reason, an important aspect of a scientist's work is disseminating results and communicating with peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the limited few who are present. Instead, most scientists present their results in peer-reviewed articles that are published in scientific journals. **Peer-reviewed articles** are scientific papers that are reviewed, usually anonymously by a scientist's colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, ethical, and thorough. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. The experimental results must be consistent with the findings of other scientists.

As you review scientific information, whether in an academic setting or as part of your day-to-day life, it is important to think about the credibility of that information. You might ask yourself: has this scientific information been through the rigorous process of peer review? Are the conclusions based on available data and accepted by the larger scientific community? Scientists are inherently skeptical, especially if conclusions are not supported by evidence (and you should be too).

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Page 1.3: Environment and Sustainability

Taking The Long View: Sustainability in Evolutionary and Ecological Perspective

Of the different forms of life that have inhabited the Earth in its three to four billion year history, 99.9% are now extinct. Against this backdrop, the human enterprise with its roughly 200,000-year history barely merits attention. As the American novelist Mark Twain once remarked, if our planet's history were to be compared to the Eiffel Tower, human history would be a mere smear on the very tip of the tower. But while modern humans (*Homo sapiens*) might be insignificant in geologic time, we are by no means insignificant in terms of our recent planetary impact. A 1986 study estimated that 40% of the product of terrestrial plant photosynthesis — the basis of the food chain for most animal and bird life — was being appropriated by humans for their use. More recent studies estimate that 25% of photosynthesis on continental shelves (coastal areas) is ultimately being used to satisfy human demand. Human appropriation of such natural resources is having a profound impact upon the wide diversity of other species that also depend on them.

Evolution normally results in the generation of new lifeforms at a rate that outstrips the extinction of other species; this results in strong biological diversity. However, scientists have evidence that, for the first observable time in evolutionary history, another species — *Homo sapiens* — has upset this balance to the degree that the rate of species extinction is now estimated at 10,000 times the rate of species renewal. Human beings, just one species among millions, are crowding out the other species we share the planet with. Evidence of human interference with the natural world is visible in practically every ecosystem from the presence of pollutants in the stratosphere to the artificially changed courses of the majority of river systems on the planet. It is argued that ever since we abandoned nomadic, gatherer-hunter ways of life for settled societies some 12,000 years ago, humans have continually manipulated their natural world to meet their needs. While this observation is a correct one, the rate, scale, and the nature of human-induced global change — particularly in the post-industrial period — is unprecedented in the history of life on Earth.

There are three primary reasons for this:

Firstly, mechanization of both industry and agriculture in the last century resulted in vastly improved labor productivity which enabled the creation of goods and services. Since then, scientific advance and technological innovation — powered by ever-increasing inputs of fossil fuels and their derivatives — have revolutionized every industry and created many new ones. The subsequent development of western consumer culture, and the satisfaction of the accompanying disposable mentality, has generated material flows of an unprecedented scale. The Wuppertal Institute estimates that humans are now responsible for moving greater amounts of matter across the planet than all natural occurrences (earthquakes, storms, etc.) put together.

Secondly, the sheer size of the human population is unprecedented. Every passing year adds another 90 million people to the planet. Even though the environmental impact varies significantly between countries (and within them), the exponential growth in human numbers, coupled with rising material expectations in a world of limited resources, has catapulted the issue of distribution to prominence. Global inequalities in resource consumption and purchasing power mark the clearest dividing line between the haves and the have-nots. It has become apparent that present patterns of production and consumption are unsustainable for a global population that is projected to reach between 12 billion by the year 2050. If ecological crises and rising social conflict are to countered, the present rates of over-consumption by a rich minority, and under-consumption by a large majority, will have to be brought into balance.

Thirdly, it is not only the rate and the scale of change but the nature of that change that is unprecedented. Human inventiveness has introduced chemicals and materials into the environment which either do not occur naturally at all, or do not occur in the ratios in which we have introduced them. These persistent chemical pollutants are believed to be causing alterations in the environment, the effects of which are only slowly manifesting themselves, and the full scale of which is beyond calculation. CFCs and PCBs are but two examples of the approximately 100,000 chemicals currently in global circulation. (Between 500 and 1,000 new chemicals are being added to this list annually.) The majority of these chemicals have not been tested for their toxicity on humans and other life forms, let alone tested for their effects in combination with other chemicals. These issues are now the subject of special UN and other intergovernmental working groups.

The Evolution of Sustainability Itself

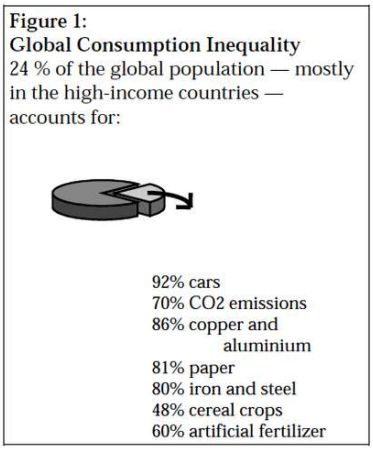
Our Common Future (1987), the report of the World Commission on Environment and Development, is widely credited with having popularized the concept of **sustainable development.** It defines sustainable development in the following ways…

- …development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- … sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the orientation of the technological development, and institutional change are made consistent with future as well as present needs.

The concept of sustainability, however, can be traced back much farther to the oral histories of indigenous cultures. For example, the principle of inter-generational equity is captured in the Inuit saying, 'we do not inherit the Earth from our parents, we borrow it from our children'. The Native American 'Law of the Seventh Generation' is another illustration. According to this, before any major action was to be undertaken its potential consequences on the seventh generation had to be considered. For a species that at present is only 6,000 generations old and whose current political decision-makers operate on time scales of months or few years at most, the thought that other human cultures have based their decision-making systems on time scales of many decades seems wise but unfortunately inconceivable in the current political climate.

Environmental Equity

While much progress is being made to improve resource efficiency, far less progress has been made to improve resource distribution. Currently, just one-fifth of the global population is consuming three-quarters of the earth's resources (Figure $Page1.3.1$). If the remaining four-fifths were to exercise their right to grow to the level of the rich minority it would result in ecological devastation. So far, global income inequalities and lack of purchasing power have prevented poorer countries from reaching the standard of living (and also resource consumption/waste emission) of the industrialized countries.



Countries such as China, Brazil, India, and Malaysia are, however, catching up fast. In such a situation, global consumption of resources and energy needs to be drastically reduced to a point where it can be repeated by future generations. But who will do the reducing? Poorer nations want to produce and consume more. Yet so do richer countries: their economies demand ever greater consumption-based expansion. Such stalemates have prevented any meaningful progress towards equitable and sustainable resource distribution at the international level. These issue of fairness and distributional justice remain unresolved.

Concepts in Environmental Science

The **ecological footprint** (EF), developed by Canadian ecologist and planner William Rees, is basically an accounting tool that uses land as the unit of measurement to assess per capita consumption, production, and discharge needs. It starts from the assumption that every category of energy and material consumption and waste discharge requires the productive or absorptive capacity of a finite area of land or water. If we (add up) all the land requirements for all categories of consumption and waste discharge by a defined population, the total area represents the Ecological Footprint of that population on Earth whether or not this area coincides with the population's home region.

Land is used as the unit of measurement for the simple reason that, according to Rees, “Land area not only captures planet Earth’s finiteness, it can also be seen as a proxy for numerous essential life support functions from gas exchange to nutrient recycling … land supports photosynthesis, the energy conduit for the web of life. Photosynthesis sustains all important food chains and maintains the structural integrity of ecosystems.”

What does the ecological footprint tell us? Ecological footprint analysis can tell us in a vivid, ready-to-grasp manner how much of the Earth’s environmental functions are needed to support human activities. It also makes visible the extent to which consumer lifestyles and behaviors are ecologically sustainable calculated that the ecological footprint of the average American is – conservatively – 5.1 hectares per capita of productive land. With roughly 7.4 billion hectares of the planet’s total surface area of 51 billion hectares available for human consumption, if the current global population were to adopt American consumer lifestyles we would need two additional planets to produce the resources, absorb the wastes, and provide general life-support functions.

The **precautionary principle** is an important concept in environmental sustainability. A 1998 consensus statement characterized the precautionary principle this way: “when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically”. For example, if a new pesticide chemical is created, the precautionary principle would dictate that we presume, for the sake of safety, that the chemical may have potential negative consequences for the environment and/or human health, even if such consequences have not been proven yet. In other words, it is best to proceed cautiously in the face of incomplete knowledge about something’s potential harm.

Some Indicators of Global Environmental Stress

- Forests **—** Deforestation remains a main issue. 1 million hectares of forest were lost every year in the decade 1980-1990. The largest losses of forest area are taking place in the tropical moist deciduous forests, the zone best suited to human settlement and agriculture. Recent estimates suggest that nearly two-thirds of tropical deforestation is due to farmers clearing land for agriculture. There is increasing concern about the decline in forest quality associated with intensive use of forests and unregulated access.
- Soil — As much as 10% of the earth’s vegetated surface is now at least moderately degraded. Trends in soil quality and management of irrigated land raise serious questions about longer-term sustainability. It is estimated that about 20% of the world’s 250 million hectares of irrigated land are already degraded to the point where crop production is seriously reduced.
- Fresh Water — Some 20% of the world’s population lacks access to safe water and 50% lacks access to safe sanitation. If current trends in water use persist, two-thirds of the world’s population could be living in countries experiencing moderate or high water stress by 2025.
- Marine fisheries — 25% of the world’s marine fisheries are being fished at their maximum level of productivity and 35% are overfished (yields are declining). In order to maintain current per capita consumption of fish, global fish harvests must be increased; much of the increase might come through aquaculture which is a known source of water pollution, wetland loss and mangrove swamp destruction.
- Biodiversity — Biodiversity is increasingly coming under threat from development, which destroys or degrades natural habitats, and from pollution from a variety of sources. The first comprehensive global assessment of biodiversity put the total number of species at close to 14 million and found that between 1% and 11% of the world’s species may be threatened by extinction every decade. Coastal ecosystems, which host a very large proportion of marine species, are at great risk with perhaps one-third of the world’s coasts at high potential risk of degradation and another 17% at moderate risk.
- Atmosphere — The Intergovernmental Panel on Climate Change has established that human activities are having a discernible influence on global climate. CO_2 emissions in most industrialized countries have risen during the past few years and countries generally failed to stabilize their greenhouse gas emissions at 1990 levels by 2000 as required by the Climate Change convention.
- Toxic chemicals — About 100,000 chemicals are now in commercial use and their potential impacts on human health and ecological function represent largely unknown risks. Persistent organic pollutants are now so widely distributed by air and ocean currents that they are found in the tissues of people and wildlife everywhere; they are of particular concern because of their high levels of toxicity and persistence in the environment.
- Hazardous wastes — Pollution from heavy metals, especially from their use in industry and mining, is also creating serious health consequences in many parts of the world. Incidents and accidents involving uncontrolled radioactive sources continue to

increase, and particular risks are posed by the legacy of contaminated areas left from military activities involving nuclear materials.

- Waste — Domestic and industrial waste production continues to increase in both absolute and per capita terms, worldwide. In the developed world, per capita waste generation has increased threefold over the past 20 years; in developing countries, it is highly likely that waste generation will double during the next decade. The level of awareness regarding the health and environmental impacts of inadequate waste disposal remains rather poor; poor sanitation and waste management infrastructure is still one of the principal causes of death and disability for the urban poor.

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Page 1.4: Environmental Ethics

Frontier Ethic

The ways in which humans interact with the land and its natural resources are determined by ethical attitudes and behaviors. Early European settlers in North America rapidly consumed the natural resources of the land. After they depleted one area, they moved westward to new frontiers. Their attitude towards the land was that of a **frontier ethic**. A frontier ethic assumes that the earth has an unlimited supply of resources. If resources run out in one area, more can be found elsewhere or alternatively human ingenuity will find substitutes. This attitude sees humans as masters who manage the planet. The frontier ethic is completely anthropocentric (human-centered), for only the needs of humans are considered.

Most industrialized societies experience population and economic growth that are based upon this frontier ethic, assuming that infinite resources exist to support continued growth indefinitely. In fact, economic growth is considered a measure of how well a society is doing. The late economist Julian Simon pointed out that life on earth has never been better, and that population growth means more creative minds to solve future problems and give us an even better standard of living. However, now that the human population has passed seven billion and few frontiers are left, many are beginning to question the frontier ethic. Such people are moving toward an environmental ethic, which includes humans as part of the natural community rather than managers of it. Such an ethic places limits on human activities (e.g., uncontrolled resource use), that may adversely affect the natural community.

Some of those still subscribing to the frontier ethic suggest that outer space may be the new frontier. If we run out of resources (or space) on earth, they argue, we can simply populate other planets. This seems an unlikely solution, as even the most aggressive colonization plan would be incapable of transferring people to extraterrestrial colonies at a significant rate. Natural population growth on earth would outpace the colonization effort. A more likely scenario would be that space could provide the resources (e.g. from asteroid mining) that might help to sustain human existence on earth.

Sustainable Ethic

A **sustainable ethic** is an environmental ethic by which people treat the earth as if its resources are limited. This ethic assumes that the earth's resources are not unlimited and that humans must use and conserve resources in a manner that allows their continued use in the future. A sustainable ethic also assumes that humans are a part of the natural environment and that we suffer when the health of a natural ecosystem is impaired. A sustainable ethic includes the following tenets:

- The earth has a limited supply of resources.
- Humans must conserve resources.
- Humans share the earth's resources with other living things.
- Growth is not sustainable.
- Humans are a part of nature.
- Humans are affected by natural laws.
- Humans succeed best when they maintain the integrity of natural processes sand cooperate with nature.

For example, if a fuel shortage occurs, how can the problem be solved in a way that is consistent with a sustainable ethic? The solutions might include finding new ways to conserve oil or developing renewable energy alternatives. A sustainable ethic attitude in the face of such a problem would be that if drilling for oil damages the ecosystem, then that damage will affect the human population as well. A sustainable ethic can be either anthropocentric or biocentric (life-centered). An advocate for conserving oil resources may consider all oil resources as the property of humans. Using oil resources wisely so that future generations have access to them is an attitude consistent with an anthropocentric ethic. Using resources wisely to prevent ecological damage is in accord with a biocentric ethic.

Land Ethic

Aldo Leopold, an American wildlife natural historian and philosopher, advocated a biocentric ethic in his book, *A Sand County Almanac*. He suggested that humans had always considered land as property, just as ancient Greeks considered slaves as property. He believed that mistreatment of land (or of slaves) makes little economic or moral sense, much as today the concept of slavery is

considered immoral. All humans are merely one component of an ethical framework. Leopold suggested that land be included in an ethical framework, calling this the land ethic.

"The **land ethic** simply enlarges the boundary of the community to include soils, waters, plants and animals; or collectively, the land. In short, a land ethic changes the role of *Homo sapiens* from conqueror of the land-community to plain member and citizen of it. It implies respect for his fellow members, and also respect for the community as such." (Aldo Leopold, 1949)

Leopold divided conservationists into two groups: one group that regards the soil as a commodity and the other that regards the land as biota, with a broad interpretation of its function. If we apply this idea to the field of forestry, the first group of conservationists would grow trees like cabbages, while the second group would strive to maintain a natural ecosystem. Leopold maintained that the conservation movement must be based upon more than just economic necessity. Species with no discernible economic value to humans may be an integral part of a functioning ecosystem. The land ethic respects all parts of the natural world regardless of their utility, and decisions based upon that ethic result in more stable biological communities.

"Anything is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends to do otherwise." (Aldo Leopold, 1949)

Hetch Hetchy Valley

In 1913, the Hetch Hetchy Valley – located in Yosemite National Park in California – was the site of a conflict between two factions, one with an anthropocentric ethic and the other, a biocentric ethic. As the last American frontiers were settled, the rate of forest destruction started to concern the public.



Figure $Page1.4.1$. Yosemite valley, California, USA.

The conservation movement gained momentum, but quickly broke into two factions. One faction, led by Gifford Pinchot, Chief Forester under Teddy Roosevelt, advocated utilitarian conservation (i.e., conservation of resources for the good of the public). The other faction, led by John Muir, advocated preservation of forests and other wilderness for their inherent value. Both groups rejected the first tenet of frontier ethics, the assumption that resources are limitless. However, the conservationists agreed with the rest of the tenets of frontier ethics, while the preservationists agreed with the tenets of the sustainable ethic.

The Hetch Hetchy Valley was part of a protected National Park, but after the devastating fires of the 1906 San Francisco earthquake, residents of San Francisco wanted to dam the valley to provide their city with a stable supply of water. Gifford Pinchot favored the dam.

> *"As to my attitude regarding the proposed use of Hetch Hetchy by the city of San Francisco…I am fully persuaded that… the injury…by substituting a lake for the present swampy floor of the valley…is altogether unimportant compared with the benefits to be derived from it's use as a reservoir.*
>
> *"The fundamental principle of the whole conservation policy is that of use, to take every part of the land and its resources and put it to that use in which it will serve the most people." (Gifford Pinchot, 1913)*

John Muir, the founder of the Sierra Club and a great lover of wilderness, led the fight against the dam. He saw wilderness as having an intrinsic value, separate from its utilitarian value to people. He advocated preservation of wild places for their inherent

beauty and for the sake of the creatures that live there. The issue aroused the American public, who were becoming increasingly alarmed at the growth of cities and the destruction of the landscape for the sake of commercial enterprises. Key senators received thousands of letters of protest.

> *"These temple destroyers, devotees of ravaging commercialism, seem to have a perfect contempt for Nature, and instead of lifting their eyes to the God of the Mountains, lift them to the Almighty Dollar." (John Muir, 1912)*

Despite public protest, Congress voted to dam the valley. The preservationists lost the fight for the Hetch Hetchy Valley, but their questioning of traditional American values had some lasting effects. In 1916, Congress passed the "National Park System Organic Act," which declared that parks were to be maintained in a manner that left them unimpaired for future generations. As we use our public lands, we continue to debate whether we should be guided by preservationism or conservationism.

The Tragedy of the Commons

In his essay, The Tragedy of the Commons, Garrett Hardin (1968) looked at what happens when humans do not limit their actions by including the land as part of their ethic. The **tragedy of the commons** develops in the following way: Imagine a pasture open to all (the 'commons'). It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. As rational beings, each herdsman seeks to maximize their gain. Adding more cattle increases their profit, and they do not suffer any immediate negative consequence because the commons are shared by all. The rational herdsman concludes that the only sensible course is to add another animal to their herd, and then another, and so forth. However, this same conclusion is reached by each and every rational herdsman sharing the commons. Therein lies the tragedy: each person is locked into a system that compels them to increase their herd, without limit, in a world that is limited. Eventually this leads to the ruination of the commons. In a society that believes in the freedom of the commons, freedom brings ruin to all because each person acts selfishly.

Hardin went on to apply the situation to modern commons: overgrazing of public lands, overuse of public forests and parks, depletion of fish populations in the ocean, use of rivers as a common dumping ground for sewage, and fouling the air with pollution.

The "Tragedy of the Commons" is applicable to what is arguably the most consequential environmental problem: global climate change. The atmosphere is a commons into which countries are dumping carbon dioxide from the burning of fossil fuels. Although we know that the generation of greenhouse gases will have damaging effects upon the entire globe, we continue to burn fossil fuels. As a country, the immediate benefit from the continued use of fossil fuels is seen as a positive component (because of economic growth). All countries, however, will share the negative long-term effects.

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Page 1.5: Environmental Justice and Indigenous Struggles

Environmental Justice

Environmental Justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.

During the 1980's minority groups protested that hazardous waste sites were preferentially sited in minority neighborhoods. In 1987, Benjamin Chavis of the United Church of Christ Commission for Racism and Justice coined the term **environmental racism** to describe such a practice. The charges generally failed to consider whether the facility or the demography of the area came first. Most hazardous waste sites are located on property that was used as disposal sites long before modern facilities and disposal methods were available. Areas around such sites are typically depressed economically, often as a result of past disposal activities. Persons with low incomes are often constrained to live in such undesirable, but affordable, areas. The problem more likely resulted from one of insensitivity rather than racism. Indeed, the ethnic makeup of potential disposal facilities was most likely not considered when the sites were chosen.

Decisions in citing hazardous waste facilities are generally made on the basis of economics, geological suitability and the political climate. For example, a site must have a soil type and geological profile that prevents hazardous materials from moving into local aquifers. The cost of land is also an important consideration. The high cost of buying land would make it economically unfeasible to build a hazardous waste site in Beverly Hills. Some communities have seen a hazardous waste facility as a way of improving their local economy and quality of life. Emelle County, Alabama had illiteracy and infant mortality rates that were among the highest in the nation. A landfill constructed there provided jobs and revenue that ultimately helped to reduce both figures.

In an ideal world, there would be no hazardous waste facilities, but we do not live in an ideal world. Unfortunately, we live in a world plagued by rampant pollution and dumping of hazardous waste. Our industrialized society has necessarily produced wastes during the manufacture of products for our basic needs. Until technology can find a way to manage (or eliminate) hazardous waste, disposal facilities will be necessary to protect both humans and the environment. By the same token, this problem must be addressed. Industry and society must become more socially sensitive in the selection of future hazardous waste sites. All humans who help produce hazardous wastes must share the burden of dealing with those wastes, not just the poor and minorities.

Indigenous People

Since the end of the 15th century, most of the world's frontiers have been claimed and colonized by established nations. Invariably, these conquered frontiers were home to people indigenous to those regions. Some were wiped out or assimilated by the invaders, while others survived while trying to maintain their unique cultures and way of life. The United Nations officially classifies **indigenous people** as those "having an historical continuity with pre-invasion and pre-colonial societies," and "consider themselves distinct from other sectors of the societies now prevailing in those territories or parts of them." Furthermore, indigenous people are "determined to preserve, develop and transmit to future generations, their ancestral territories, and their ethnic identity, as the basis of their continued existence as peoples in accordance with their own cultural patterns, social institutions and legal systems." A few of the many groups of indigenous people around the world are: the many tribes of Native Americans (i.e., Navajo, Sioux) in the contiguous 48 states, the Inuit of the arctic region from Siberia to Canada, the rainforest tribes in Brazil, and the Ainu of northern Japan.

Many problems face indigenous people including the lack of human rights, exploitation of their traditional lands and themselves, and degradation of their culture. In response to the problems faced by these people, the United Nations proclaimed an "International Decade of the World's Indigenous People" beginning in 1994. The main objective of this proclamation, according to the United Nations, is "the strengthening of international cooperation for the solution of problems faced by indigenous people in such areas as human rights, the environment, development, health, culture and education." Its major goal is to protect the rights of indigenous people. Such protection would enable them to retain their cultural identity, such as their language and social customs, while participating in the political, economic and social activities of the region in which they reside.

Despite the lofty U.N. goals, the rights and feelings of indigenous people are often ignored or minimized, even by supposedly culturally sensitive developed countries. In the United States many of those in the federal government are pushing to exploit oil resources in the Arctic National Wildlife Refuge on the northern coast of Alaska. The “Gwich’in,” an indigenous people who rely culturally and spiritually on the herds of caribou that live in the region, claim that drilling in the region would devastate their way of life. Thousands of years of culture would be destroyed for a few months’ supply of oil. Drilling efforts have been stymied in the past, but mostly out of concern for environmental factors and not necessarily the needs of the indigenous people. Curiously, another group of indigenous people, the “Inupiat Eskimo,” favor oil drilling in the Arctic National Wildlife Refuge. Because they own considerable amounts of land adjacent to the refuge, they would potentially reap economic benefits from the development of the region.



Figure $Page1.5.1$. An Inupiaq woman, Nome, Alaska, c. 1907. Credit: This work is in the Public Domain, CC0

The heart of most environmental conflicts faced by governments usually involves what constitutes proper and sustainable levels of development. For many indigenous peoples, sustainable development constitutes an integrated wholeness, where no single action is separate from others. They believe that sustainable development requires the maintenance and continuity of life, from generation to generation and that humans are not isolated entities, but are part of larger communities, which include the seas, rivers, mountains, trees, fish, animals and ancestral spirits. These, along with the sun, moon and cosmos, constitute a whole. From the point of view of indigenous people, sustainable development is a process that must integrate spiritual, cultural, economic, social, political, territorial and philosophical ideals.

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Page 1.S: Environmental Science (Summary)

Summary

Science attempts to describe and understand the nature of the universe in whole or in part. Science has many fields; those fields related to the physical world and its phenomena are considered natural sciences. A hypothesis is a tentative explanation for an observation. A scientific theory is a well-tested and consistently verified explanation for a set of observations or phenomena. A scientific law is a description, often in the form of a mathematical formula, of the behavior of an aspect of nature under certain circumstances. Two types of logical reasoning are used in science. Inductive reasoning uses results to produce general scientific principles. Deductive reasoning is a form of logical thinking that predicts results by applying general principles. The common thread throughout scientific research is the use of the scientific method. Scientists present their results in peer-reviewed scientific papers published in scientific journals. Science can be basic or applied. The main goal of basic science is to expand knowledge without any expectation of short-term practical application of that knowledge. The primary goal of applied research, however, is to solve practical problems.

Sustainability refers to three simple concerns: the need to arrest environmental degradation and ecological imbalance, the need not to impoverish future generations and the need for quality of life and equity between current generations. Added up, these core concerns are an unmistakable call for transformation. Business-as-usual is no longer an option. The concept of ethics involves standards of conduct. These standards help to distinguish between behavior that is considered right and that which is considered wrong. The ways in which humans interact with the land and its natural resources are determined by ethical attitudes and behaviors. A frontier ethic assumes that the earth has an unlimited supply of resources. Environmental ethic includes humans as part of the natural community rather than managers of it. Sustainable ethic assumes that the earth's resources are not unlimited and that humans must use and conserve resources in a manner that allows their continued use in the future. Countries are categorized by a variety of methods. During the Cold War period, the United States government categorized countries according to each government's ideology and capitalistic development. Current classification models utilize economic (and sometimes other) factors in their determination. Environmental justice is achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment. Many problems face indigenous people, including: lack of human rights, exploitation of their traditional lands and themselves, and degradation of their culture. Despite the lofty U.N. goals, the rights and feelings of indigenous people are often ignored or minimized, even by supposedly culturally sensitive developed countries.

Review Questions

1. Scientific research that produces knowledge without any immediate practical use is specifically known as…
   A. Basic science
   B. Applied science
   C. Hypothesis-based science
   D. Descriptive science
   E. Retrospective science
2. Which one of the following fulfills the definition of a hypothesis?
   A. Removing invasive species will result in greater biodiversity.
   B. Introducing invasive species will harm an ecosystem.
   C. Invasive species are non-native species that alter ecosystems.
   D. Introducing invasive species will decrease biodiversity by displacing native species
   E. Ecosystem productivity will decrease when invasive species are introduced.
3. Which one of the following is consistent with the frontier ethic?
   A. Expanding the area covered by a wildlife sanctuary
   B. Protecting a natural area as a national park
   C. Sustainable logging of a forest
   D. Transferring ownership of forestland from private ownership to the federal government
   E. Extracting copper ore from mineral-rich deposit in a landscape rich in biodiversity

4. Which one of the following suggests that when the effects of a human activity are poorly understood, we must presume that some level of harm may exist to the environment, and thus must proceed with that activity carefully?
   A. Sustainability ethic
   B. Precautionary principle
   C. Environmental harm dictum
   D. Environmental injustice
   E. Presumptive principle
5. Which one of the following demonstrates the concept of the "tragedy of the commons"?
   A. Competing companies log as many trees as possible for financial gain until no trees are left
   B. Public forest land is sold to a privately-owned investor group
   C. Logging forests is dangerous work and ends up killing or injuring many workers
   D. A careless hiker accidentally starts a wildfire that destroys hundreds of acres of forest
   E. Government regulations lead to conditions that increase the risk of forest fire on public lands
6. The equal sharing of Earth's resources is specifically known as…
   A. Environmental justice
   B. Sustainability
   C. Environmental equity
   D. Ecological footprinting
   E. Mutualism
7. John Muir's position on the proposed development in the Hetch Hetchy Valley of California in the early 1900s would best match which one of the following?
   A. Frontier ethic
   B. Sustainable ethic
   C. Land ethic
   D. Ethos ethic
   E. Darwinian ethic
8. Which one of the following is an example of inductive reasoning?
   A. Every lion you've seen on TV hunts gazelles, therefore all lions hunt gazelles.
   B. All tigers are mammals. All mammals are vertebrates. Therefore, tigers are vertebrates.
   C. Every lake contains water; therefore, Crater Lake contains water.
   D. Only plants have flowers. Tulips are a plant because they have flowers.
   E. The sun emits energy in the form of photons. Visible light is made of photos and thus light is a type of energy.
9. The fair treatment and meaningful involvement of all people regarding enforcement and implementation of environmental regulations and policies is known as what?
   A. *Quid pro quo*
   B. Environmental justice
   C. Environmental equity
   D. *Habeas corpus*
   E. Ecologic inclusiveness
10. People and their culture that have existed continuously dating back to a time before their land was invaded or colonized by other societies are known as…
    A. Endemic
    B. Indigenous
    C. Exotic
    D. Incunable
    E. Invidious

See Appendix for answers

11. What is science?
12. Describe the process of scientific method.
13. What are inductive reasoning and deductive reasoning?
14. Describe the goals of basic and applied science.
15. Give one example of the link between basic and applied research.
16. What are peer-reviewed articles?
17. Explain the following terms: hypothesis, falsifiability, scientific law.
18. Name some indicators of global environmental stress.
19. Define sustainability.
20. Explain the following terms: frontier ethic, land ethic, environmental ethic.
21. What are developed countries according to the World Bank classification?
22. Define environmental justice.

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2: The Physical World

Learning Objectives

After completing this chapter, you will be able to

1. Explain the geological structure and dynamics of planet Earth.
2. Describe the importance of glaciation and other geological forces in modifying the landscapes of Canada.
3. Outline the four major elements of Earth's water cycle.
4. Describe the atmosphere and its circulation.
5. Explain the elements of climate and weather.

Introduction

In this chapter we examine various aspects of the physical world, including the origin of planet Earth and the nature and dynamics of its physical attributes. Understanding these subjects is important in environmental science because they provide a context for interpreting many of the changes that are being caused by human activities.

Planet Earth

The universe is thought to have originated as many as 12-15 billion years ago during a ginormous cataclysm known as the "big bang." Initially, virtually all of the mass of the nascent universe consisted of the two lightest elements, hydrogen and helium, which existed as an extremely diffuse gaseous mass. Eventually, under the pervasive influence of gravity, the hydrogen and helium were aggregated into immense masses that became increasingly compressed under enormously high pressure and temperature. When the pressure and temperature were sufficiently intense, nuclear fusion reactions began to occur within the masses, at which point they had become young stars. In addition to releasing immense quantities of energy, the fusion reactions caused the formation of heavier elements. Because of these processes, there are now 88 naturally occurring elements. Hydrogen and helium are still, however, the most abundant elements, comprising more than 99.9% of the mass of the universe.

The Sun is an ordinary star, one of billions of billions that exist in the universe. The Sun, its eight orbiting planets, plus miscellaneous comets, meteors, asteroids, and other materials (such as space dust) are collectively known as the solar system. This particular region of the universe is organized and held together by a balance of the attractive force of gravitation and counteracting influences associated with rotation and orbiting (these same forces, along with continuing expansion from the initial big bang, also organize the universe). The age of the solar system (and of Earth) is at least 4.6 billion years.

Earth is the third-closest planet to the Sun. Earth is a dense planet, as are other so-called terrestrial planets located relatively close to the Sun: Mercury, Venus, and Mars. The mass of these planets consists almost entirely of heavier elements such as iron, nickel, magnesium, aluminum, and silicon. These inner planets were formed by a selective condensing of heavier elements out of the primordial planetary nebula (the disk of gases and other matter that slowly rotated around the Sun during the early stages of formation of its solar system). This happened because the inner planets were subjected to relatively intense heating by solar radiation, which caused lighter gases such as hydrogen and helium to disperse further away, to the extent that they ended up mostly in the outer, cooler planets. Meanwhile the terrestrial planets retained heavier elements. Consequently, the more distant planets in the solar system, such as Jupiter and Saturn, are relatively large, gaseous, and diffuse in character. Most of their volume is composed of an extensive atmosphere of hydrogen and helium, although these planets may contain heavier elements in their core.

Earth is the only place in the universe that is definitely known to sustain life. It is quite possible, however, that other planets in the cosmos also sustain life. Although there is no direct evidence of this, many scientists consider it likely that life has evolved elsewhere. One estimate suggests that the universe contains 10^{22} (10,000 billion billion) stars, with perhaps 10% of them having planetary systems (10^{21}systems). With such incredibly large numbers, it is highly probable that at least some of the billions of billions of other planetary systems support suitable conditions for a genesis of life, in addition to what occurred on Earth.

Earth is a spherical body with a diameter of about 12,740 km. It revolves around the Sun in an elliptical orbit, at an average distance of about 149 million km, completing an orbit in 365.26 days, or one year. Earth also rotates on its axis every 24 hours, or one day. Its single moon has a diameter of about 3,474 km and a mass about 2% that of Earth. The Moon revolves around Earth in an elliptical orbit at an average distance of about 385,000 km, completed every 27.3 days (the lunar month).

The sphere of Earth is composed of four layers—the core, mantle, lithosphere, and crust—arranged in concentric layers like an onion. The massive core has a diameter of about 3,500 km and is composed of hot, molten metals, particularly iron and nickel. The internal heat of Earth is thought to be generated by the slow, radioactive decay of unstable isotopes of certain elements, such as uranium.

The mantle is a less dense region that encloses the core. It is about 2,800 km thick and composed of minerals in a plastic, semi-liquid state known as magma. The mantle contains relatively light elements, notably silicon, oxygen, and magnesium, occurring as various mineral compounds. Magma from the upper mantle sometimes erupts to the surface at mountainous vents known as volcanoes and is usually spewed to the surface as lava, which cools to form basaltic rock.

The next layer, the lithosphere, is only about 80 km thick and is made of rigid, relatively light rocks, especially basaltic, granitic, and sedimentary ones. These rocks contain elements found in the mantle as well as enriched quantities of aluminum, carbon, calcium, potassium, sodium, sulphur, and other lighter elements.

The outermost layer is known as the crust. Oceanic crust is relatively thin, averaging 10–15 km, while continental crust is 20–60 km thick. Earth's crust has an extremely complex mineralogical composition, in contrast to the mantle and especially the core, which are thought to be relatively uniform in structure and constitution. The most abundant elements in the crust are oxygen (45%), silicon (27%), aluminum (8.0%), iron (5.8%), calcium (5.1%), magnesium (2.8%), sodium (2.3%), potassium (1.7%), titanium (0.86%), vanadium (0.17%), hydrogen (0.14%), phosphorus (0.10%), and carbon (0.032%).

The rocks forming the crust can be grouped into three basic types: igneous, sedimentary, and metamorphic. Igneous rocks include basalt and granite, which are formed by the cooling of molten magma. The mineral forms depend on the rate of cooling plus other factors. Basalt is a heavy, dark, extremely fine-grained rock that sometimes forms vertical, columnar structures. Basaltic rocks are the major constituent of oceanic crust, originating in submarine places where magmic lava erupts to the sea-floor surface, such as deep-ocean spreading zones and abyssal volcanoes. Basalt can also be formed at terrestrial volcanoes – for instance, it is the basement rock of the Hawaiian archipelago and other volcanic islands. Granitic rocks dominate the continental crust, are typically relatively light in colour and density, and are coarser-grained, with readily distinguishable crystals. The complex crystalline structure includes the minerals quartz and feldspar, and mica and hornblende are often present.

Sedimentary rocks include limestone, dolomite, shale, sandstone, and conglomerates. These form from particles eroded from other rocks or from precipitated minerals such as calcite ($CaCO_3$) that become lithified (turned into stone) under great pressure in deep oceanic deposits. Sedimentary rocks typically overlie basaltic or granitic rocks.

Metamorphic rocks are formed from igneous or sedimentary ones that were changed under the combined influences of massive geological heat and pressure. These conditions were encountered when the primary rocks were carried deep into the lithosphere by crustal movements, such as those associated with mountain building (described below). Gneiss, for example, is a metamorphic rock derived from granite, while marble is derived from limestone, and slate from shale. About 30% of Earth's surface is covered by the solid substrates of continents and islands. The other 70% of Earth's surface is liquid water, almost all of which is oceanic. In addition, Earth's dense sphere is immersed in a gaseous envelope known as the atmosphere, which extends to a distance of about 1,000 km. However, about 99% of the mass of the atmosphere occurs within 30 km of the planet's surface.

Geological Dynamics

Throughout its history, Earth has been subject to enormous geological forces that have greatly affected its mineralogical composition and surface features. The predominant influences are tectonic forces, which are associated with crustal movements and other processes that cause structural deformation of rocks and minerals. Geological forces also cause the continents and their underlying plates to slowly move about Earth's surface, much like rafts of solid rock riding upon a sea of plastic magma. Mountain ranges are built where crustal plates collide and push up surface rocks.

Earthquakes and volcanoes are also tectonic phenomena, which influence Earth's crust and surface with extremely powerful, sometimes disastrous events. Other massive geological forces include rare, cataclysmic strikes into our planet by meteorites and extensive glaciation associated with cooling of the climate. Slower but still pervasive geological forces are erosion (caused by water, wind, and gravity) and weathering (the fracturing of rocks and dissolution of minerals).

Over geological time, these various physical processes have profoundly influenced the character of Earth. Geological forces continue to have enormous influences on Earth and its ecosystems, over both short- and long-term time scales. Environmental

changes associated with these geological dynamics provide a natural context for the substantial changes that humans are now causing through their economic activities.

Meteorites

Earth is frequently struck by fast-moving rocky or metallic objects from space known as meteorites. Although meteorites are relatively small objects (by planetary standards), they have immense momentum because of their speed, which typically ranges from 10-100 km/s. The smallest, most numerous meteorites reaching Earth typically burn up or explode in the atmosphere because of heat generated by friction, but larger ones may survive to impact the surface. It has been estimated that each day a meteorite weighing at least 100 g strikes the surface somewhere in Canada.

Very large meteorites are extremely rare, but if the impact the surface enormous damage is caused. The impact site is typically obliterated and a large crater is formed because vast amounts of crustal materials are ejected into the atmosphere. Immense sea waves can also be caused by a meteorite impact. Several dozen large meteorite craters are known in Canada. The largest is an ovoid depression with a diameter of 140 km near Sudbury, Ontario, caused by a meteorite strike occurring about 1,850 million years ago (Mya), and a doughnut-shaped lake with a diameter of 70 km at Manicouagan, Quebec, from an impact about 215 Mya ago. These extraordinary events must have caused tremendous damage to the species and ecosystems of the time.

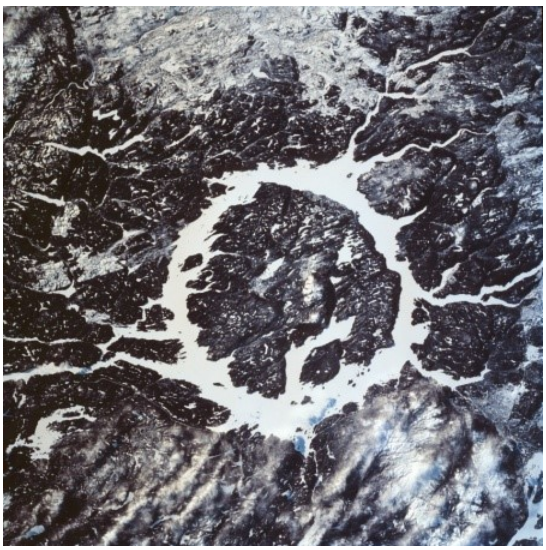


Image 3.1. View of Lake Manicouagan, Quebec. This doughnut-shaped lake is an impact crater from a meteorite impact that occurred about 215 million years ago. This image was taken from the space shuttle Endeavour on May 25, 2011. Source: NASA photo 714196. http://www.dvidshub.net/image/714196/earth-observations-lake-manicouagan-quebec-taken-during-sts-99#.VBCO4VIg99A

Earth's evolutionary history has been punctuated by a number of catastrophic events of mass extinction, during which most of the existing biota disappeared in a short period of time, to be later replaced by new species (see Chapter 6). Paleontologists recognize these cataclysms by the occurrence of rapid changes in the fossil record, which point to a transition between stages in the geological time scale (Table 3.1). According to surviving evidence, the most intense mass extinction event occurred 245 million years ago at the end of the Permian period, when an astonishing 96% of species may have become extinct. Another mass extinction occurred 65 million years ago at the end of the Cretaceous period, when perhaps 76% of species became extinct, including the last of the dinosaurs. According to one theory, the end-of-Cretaceous extinctions were caused when a 10–15 km wide meteorite impacted the Earth. This resulted in that huge amounts of fine dust being spewed into the upper atmosphere, which caused a severe cooling of the climate that large animals and many ecosystems could not tolerate. Some geologists believe that the impact site was near the Yucatan coast of Mexico, where a buried, 170-km-wide ring structure exists, dated to about 65 million years old. Although controversial, the theory of rare, meteorite-caused catastrophes has also been used to explain other mass extinctions in the geological record.

Era	Period	Epoch	Time (Mya)
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	1.6
	Tertiary	Pliocene	5
		Miocene	26
		Oligocene	38
		Eocene	54
		Paleocene	65
Mesozoic	Cretaceous		140
	Jurassic		210
	Triassic		245
Paleozoic	Permian		290
	Carboniferous		365
	Devonian		413
	Silurian		441
	Ordovician		504
	Cambrian		570
Precambrian	Proterozoic		2,400
	Archaean		>4,500

Table 3.1. The Geological Time Scale. The divisions between geological time stages are assigned on the basis of rapid changes in mineralogy and in species composition of the fossil record. These are related to events of mass extinction, which were followed by the evolutionary radiation of new species and families. The record is most detailed for relatively recent times, because the fossil remains are more complete. Time is given in Mya (millions of years ago) and indicates the beginning of each time stage. For example, the Holocene epoch ranges from 0.01 Mya (10,000 years ago) to the present; the Pleistocene ranges from 1.6 million years ago to 0.01 Mya.

Plate Tectonics

The theory of plate tectonics concerns the dynamics of surface crustal materials. In simple terms, this theory suggests that the crust and mantle behave as an enormous convecting system that, at the surface, is characterized by extremely slow movements of huge plates of rigid crustal material. The plates move from zones where they are created by an upwelling of magma from the upper mantle, toward other zones where they are destroyed by downward movement into the upper the mantle. In the creation zones, the plastic magma rises to the surface, solidifies, and then extends laterally in a process known as sea-floor spreading. In the down-welling zones, there is a subduction of sea-floor crust back down into the mantle, where it is re-melted and convected laterally. The magma may eventually reach another upwelling region and again be carried to the crust. The slowly moving, rigid plates of surface crust have a basement of basaltic rock, with lighter, granitic-based continents rafting on the surface of some of the oceanic plates (Figure 3.1).

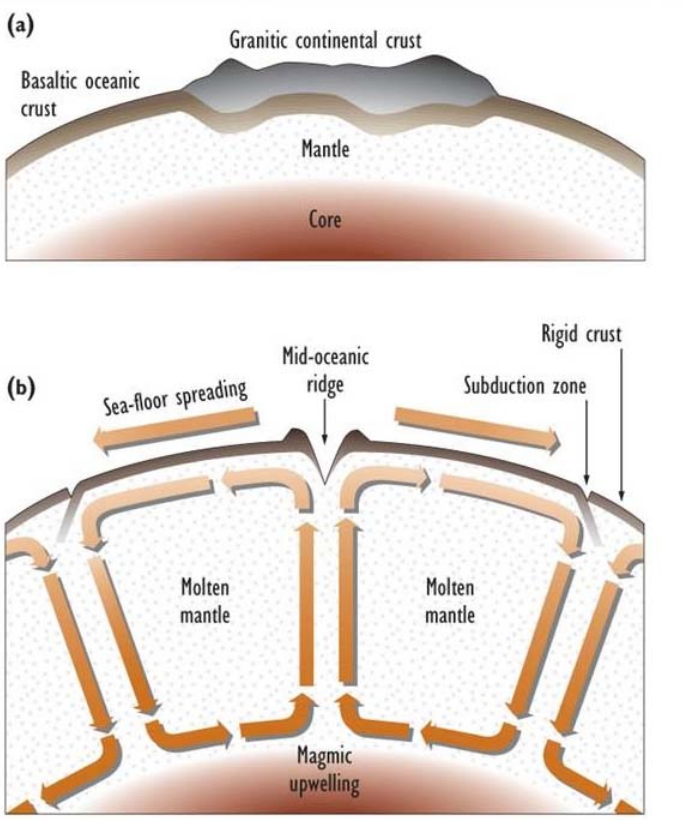


Figure 3.1. Tectonic Forces. (a) The continents are viewed as granitic islands that are rafting upon underlying plates of basaltic oceanic crust. (b) Heat and density gradients in the mantle cause a slow, convective circulation to develop in the molten magma. This circulation forms new basaltic crust at zones of magmic upwelling known as mid-oceanic ridges, followed by lateral sea-floor spreading and eventual subduction back to the mantle at the boundary with another crustal plate.

For example, in the Atlantic Ocean, about halfway between the Americas and Europe and Africa, a deep-sea geological structure called the Mid-Atlantic Ridge runs in a roughly north to south direction. This abyssal ridge is a zone of sea-floor spreading, from which the two continental regions are diverging at a slow but steady rate of 2-4 cm/year. In essence, the Atlantic ocean is widening at this rate, which is equivalent to 2-4 meters per century.

In contrast, parts of the continental landmass in the western Americas are riding on regions of plates that are subducting beneath the oceanic Pacific Plate. However, along most of southwestern North America, the Pacific and North American Plates are moving in opposite but parallel directions. This is causing southern California and the Baja Peninsula to slowly move northward relative to the rest of the continent. This process is occurring along an extended but narrow zone of contact between the plates (a fault) known as the San Andreas Fault.

These tectonic forces result in frequent earthquakes and volcanic eruptions along the Pacific coasts of North and South America, the Aleutians, and eastern Asia. This geologically active region around the Pacific Ocean is referred to as the “ring of fire” because of its many volcanoes. In addition to these discrete but intense geological events, there is active building of the relatively young mountains in this region. The mountain building is caused by crustal materials being pushed upward in regions where continents and oceanic plates are colliding with each other. In a similar manner, the lofty Himalayas of southwestern Asia were and still are being created by immense uplifting forces that are generated as the northward-drifting Indian subcontinent pushes into the larger Asian landmass.

It is thought that the continents were a single contiguous mass during the Permian period, about 290 million years ago. This primeval super-continent, referred to as Pangaea, was surrounded by a single, global ocean. However, divergent forces of crustal plates moving in different directions then pulled Pangaea apart, initially into two masses known as Laurasia and Gondwanaland, and then into the existing continents of North and South America, Africa, Eurasia, Australia, and Antarctica.

An earthquake is a trembling or movement of the Earth caused by a sudden release of geological stresses at some point within the crust or upper mantle. Earthquakes are most often caused when crustal plates slip across or beneath each other at their faults, but they can also be caused by a volcanic explosion. Although their seismic energy can affect a large area, earthquakes have a spatial focus, known as the epicentre and defined as the surface position lying above the deep point of energy release. An intense earthquake can cause great damage to buildings, and the collapsing structures, fires, and other destruction can take a great toll on people. In 1556 an earthquake struck Shanxi Province in China and caused about 830,000 deaths, making it the most deadly earthquake in recorded history. The most famous catastrophic earthquake in North America was the San Francisco event in 1906, caused by slippage along the San Andreas Fault, which killed 503 people and resulted in tremendous physical damage. However, other earthquakes during the twentieth century resulted in much greater losses of human lives, including one in 1976 that killed 242,000 people in Tangshan, China; another in 1927 that killed 200,000 in Nan-Shan, China; and one in Tokyo–Yokohama, Japan, that killed 200,000 in 1926. Notable recent earthquakes include one in Kobe, Japan (1995) that killed 5,500 people, another in Kashmir (2005) that killed 79,000 people, one in Sichuan, China (2008) that killed 70,000 people, and one in the Tohuku region of Japan (2011) that generated a tsunami (seismic sea wave) that killed 16,000 people.

The events in San Francisco (1906) and Tokyo (1926) affected large cities. The powerful tremors caused great damage, partly because of weak architectural designs that were unable to withstand the strong forces. In both cases, however, about 90% of the actual destruction resulted from fires. Earthquakes can also cause soil to lose some of its mechanical stability, resulting in destructive landslides and subsidence (sinking) of land and buildings.

Undersea earthquakes can trigger a fast-moving, sea-surface phenomenon known as a tsunami or seismic sea wave. A tsunami is barely noticeable at sea, but it can become gigantic when the wave reaches shallow water and piles up to heights that can swamp coastal villages and towns. In 1929, an earthquake off eastern Canada generated a seismic sea wave that killed 29 people in Newfoundland and Cape Breton. In 1946, a large earthquake centred on Umiak Island in the Aleutian Islands caused a tsunami to strike Hawaii, 4,500 km away, with an 18 m crest. In 2004, a tsunami in the Indian Ocean killed more than 225,000 people (see Global Focus 3.1).

Global Focus 3.1: A Killer Tsunami

A tsunami, or seismic sea wave, is a great surge of the ocean's surface caused by an underwater earthquake. A tsunami may be almost indiscernible in deep water of the open ocean, but it can become enormous when it reaches shallow coastal water and builds to a height capable of causing massive destruction. The greatest tsunami of recent times was triggered by an undersea, so-called "megathrust" earthquake on December 26, 2004. Its epicentre was located about 40 km off the coast of Aceh in northern Sumatra, an Indonesian island, and it registered a massive 9.2 on the Richter scale (making it the largest earthquake in 40 years). The tremor generated an immense tsunami (actually, a close series of individual waves) that gathered to a height up to 30 m when it impacted shallow-sloping coasts of countries fringing the Indian Ocean. Unfortunately, none of the countries that bore the brunt of the devastation were forewarned of the impending catastrophe, so no action was taken to move people from low-lying coastal areas to higher ground. This happened mostly because there was no tsunami-detection system in the Indian Ocean, although negligence was also involved because the extremely large earthquake should have alerted civil authorities to a potential catastrophe.

The colossal tsunami waves were moving at speeds of about 60 km/hr when they impacted the shore. They caused widespread devastation and more than 225,000 deaths by drowning and injuries caused by floating debris and collapsing buildings. The hardest-hit places were Sumatra (which suffered at least 168,000 dead and missing), Sri Lanka (35,000), the eastern coast and islands of India (18,000), and Thailand (8,000). At least 7,000 of the deaths were tourists from developed countries who were visiting coastal resorts during their holiday break. In addition to the mortality, tens of millions of people were displaced from their homes and livelihoods by the flooding. In many of the worst-hit places, the damage was made much more severe because of increased coastal vulnerability caused by the removal of previously abundant mangrove forest, mostly to develop tourist resorts and brackish ponds for shrimp aquaculture. Where mangroves remained intact, the coastal forest provided a sea-wall that helped to absorb much of the force of the tsunami, providing a measure of protection to areas further inland.

Responding to the overwhelming toll of death and destruction, citizens and governments of many non-affected countries delivered large donations of aid for rescue and subsequent recovery, including money (pledges totalled about US$5.4 billion), specialized rescue personnel, food and water, and materials for reconstruction. From the environmental perspective, important

lessons to be learned from this devastating tsunami include the facts that natural disasters are unpredictable and inevitable, and that the ensuing destruction can be made much worse by inappropriate land-use practices and a lack of emergency planning and response capability.



Image 3.2. A devastated village on the coast of Aceh, Sumatra, after the killer tsunami of December 26, 2004. Source: image by P.A. McDaniel, United States Navy, ID 050102-N-9593M-040; https://commons.wikimedia.org/wiki/File%3AUS_Navy_050102-N-9593M-040_A_village_near_the_coast_of_Sumatra_lays_in_ruin_after_the_Tsunami_that_struck_South_East_Asia.jpg

A volcano is a vent in the surface from which molten lava flows onto the ground and liquid, solid, and gaseous materials are ejected into the atmosphere. The largest eruptions can literally explode a volcanic mountain, ejecting immense quantities of material into the environment and causing enormous damage and loss of life. For example, an eruption of Mount Vesuvius in the year 79 CE (Common Era) buried the Roman city of Pompeii, killing almost all of its inhabitants. A 1902 explosion of Mont Pelée on the Caribbean island of Martinique killed 30,000 people.

The greatest eruption of modern times was that of Tambora, a volcano in Indonesia that exploded in 1815 and blew more than 300 km^3 of material into the atmosphere (including the top 1,300 m of the mountain). Some of the finer particulates of this massive eruption were blown into the upper atmosphere (the stratosphere), causing an increase in Earth's reflectivity that resulted in global cooling. The year 1816 became known as the "year without a summer" in Europe and North America because of its unusually cool and wet weather, including frost and snowfall during the summer months.

Another famous Indonesian eruption was that of Krakatau in the Sunda Strait in 1883, which ejected 18-21 km^3 of material as high as 50-80 km into the atmosphere. The 30-m tsunami associated with this eruption killed about 36,000 people in coastal villages.

Large volcanic eruptions can also disturb great expanses of forest and other ecosystems. For instance, the 1980 explosion of Mount St. Helen's in the state of Washington blew down about 21,000 hectares of coniferous forest and otherwise damaged another 40,000 ha. Mudslides also devastated large areas, and a vast region was covered by particulate debris (known as tephra) that settled from the atmosphere.

Some volcanoes produce chronic lava flows and venting of gases. These volcanoes tend to form distinctive, cone-shaped mountains from their accumulated lava, which solidifies into finely crystalline, glassy rocks. An active example of this spectacular process is Mount Kilauea in Hawaii, which sometimes erupts continuously for years. The slowly flowing lava from these volcanoes can destroy buildings and vegetation but is not otherwise dangerous because people and animals can avoid the molten streams.

Glaciation

Glaciers, or persistent sheets of ice, are common features in high-latitude environments of the Arctic and Antarctic. They also occur at high altitude on mountains, even in tropical countries such as New Guinea and Peru. Glaciers are formed from a deep, persistent

snowpack, which becomes compressed into ice as its weight accumulates. Most glaciers occur on land, but some also extend onto the ocean. At the present time, about 10% of the land surface of Earth is covered with glaciers, the largest of which are the continental ice sheets of Antarctica. The largest glaciers in the Northern Hemisphere are in Greenland, but parts of Baffin and Ellesmere Islands in the Canadian Arctic are also covered with glacial ice, as are some mountainous areas in western Canada.

Glaciation refers to an extensive advance of ice sheets, caused by a period of extended global cooling sometimes referred to as an ice age. There have been a number of glacial periods during geological history, although details are known only about the most recent glaciation because it obliterated most traces of earlier events. The most recent glacial period, known as the Wisconsin, began about 85,000 years ago and ended about 11,000 years ago.

At the height of the Wisconsin glaciation, ice covered about 30% of Earth's land surface, including almost all of what is now Canada, as well as extensive areas of the continental shelf that are now beneath the ocean. The latter occurred because sea level was about 120 m lower during that glaciation as a result of so much water being tied up in ice on land. The greatest ice mass in Canada was the Laurentide Ice Sheet, which reached a thickness of about 4 km. The Cordilleran Ice Sheet of the western mountains contained ice up to 2 km thick.

The present Holocene (recent; Table 3.1) epoch is relatively warm and ice-free and is referred to as an interglacial stage. Climate has not, however, been uniformly warm during the present interglacial. For example, the period of about 1450 to 1850 is known as the Little Ice Age because of its relatively cool climate. During that period there was a moderate expansion of glaciers and snowfields in many parts of the world, including the Arctic regions and western mountains of Canada.

Glaciers are extremely erosive forces that crush, scour, and excavate the underlying terrain with their massive weight and ponderous movements. Glaciers also transport huge quantities of excavated debris around the landscape. These solid materials are eventually deposited when the glaciers melt, tumbling from the ablating (melting) ice mass or being carried away by meltwater running in streams and rivers. Extensive deposits of glacial debris are common over almost all of Canada, often occurring as distinctive landforms, such as the following:

- moraines, which are a series of long, mounded hills, usually lying perpendicular to the flow of the regional glacier, and containing mixed rocky debris known as till
- drumlins, or teardrop-shaped hills that are elongated in the direction of movement of the glacier and are composed of a mixture of rocky materials
- eskers, which are long, serpentine mounds of crudely sorted debris that was deposited by a river flowing beneath a glacier
- erratics, or rounded boulders of various sizes that are incongruously scattered over the landscape
- long U-shaped valleys in mountainous terrain, which were carved from pre-existing river valleys by the erosive forces of a glacier
- fiords, which are long, narrow, steep-sided inlets of the ocean that were carved by outlet glaciers descending from a much larger ice sheet at higher altitude
- outwash plains, which contain a mixture of materials, ranging in size from rocks to sand or clay, that were deposited over a relatively wide area by streams and rivers fed by glacial meltwaters
- the former basins of large lakes of glacial meltwater, which today are characterized by flat, fine-grained, often fertile plains (Southern Manitoba has extensive former lakebeds of postglacial Lake Agassiz, while flat areas in southern Ontario and Quebec were once part of the postglacial basins of what are now the Great Lakes and St. Lawrence River.)

The tremendous ice sheets that once obliterated almost all of Canada were largely gone by 8,000 to 10,000 years ago, although glacial remnants still occur on islands in the Arctic and on mountains of western Canada. The Canadian landscape has been profoundly shaped by the impressive geological signatures of the advance and retreat of the immense continental glaciers of times past. Since then, the terrain and landforms have been greatly modified by other geological forces, such as erosion and weathering, and by the redevelopment of ecosystems after the retreat of the immense ice sheets. However, compared with the effects of the Wisconsin and previous glaciers, those forces have had a relatively small influence on the enduring character of the landscapes and coastal seascapes of Canada.



Image 3.3. During the most recent, Wisconsin glaciation, almost all of Canada was covered by glaciers. Remnant glaciers still occur, such as this ice cap on Ellesmere Island. Source: B. Freedman.

Weathering and Erosion

Meteorite impacts, earthquakes, volcanic explosions, and glaciation are all tremendous geological forces – they are capable of obliterating both natural and anthropogenic ecosystems. However, less forceful geological dynamics are also important, although they exert their influences more pervasively, by operating relatively slowly over longer time scales rather than as extremely destructive events.

Weathering refers to physical and chemical processes by which rocks and minerals are broken down by environmental agents. Non-biological (abiotic) forces of weathering include rain, wind, and temperature changes (especially freeze-thaw cycles). Biological forces include the rock-cracking powers that are exerted by plant roots. Weathering proceeds by the fracturing of rocks and by the solubilization (chemical decomposition) of minerals by acidic rainwater and by corrosive excretions of plant roots and microorganisms.

Erosion refers to the removal of rocks and soil through the actions of gravity, flowing water, ice, and wind. Erosion is a pervasive geological process, occurring at various rates in all environments. Usually it is gradual, occurring as particles are slowly removed by flowing water or blowing wind, or when dissolved minerals are carried away by underground flows of water. However, erosion also occurs as mass events, such as a landslide in steep terrain. Over extremely long periods of time, weathering and erosion tend to influence the landscape towards a relatively flat and homogeneous condition known as a peneplain.

Even geological features as immense as mountains are slowly eroded away, with their enormous mass gradually descending to be deposited in lower regions. For instance, the Precambrian Shield that is so extensive in regions of Canada is composed of the granitic basement rocks of ancient mountains that were slowly eroded away by the actions of water, wind, and glaciers. The somewhat less ancient hills of the Appalachians of eastern North America, which extend into New Brunswick, Nova Scotia, and Newfoundland, are also the eroded relics of a once-great mountain range. The youngest mountain range in North America, the Rocky Mountains, extends from the western United States north into Alberta, British Columbia, the Yukon, and the western Northwest Territories. The Rockies still have many towering, sharp peaks because they have not yet been much reduced by the inexorable, mass-wasting forces of erosion.

The rates of natural weathering and erosion is influenced by many factors, including the hardness of rocks, degree of consolidation of soil and sediment, amount of vegetation cover, rate of water flow, slope of the land, speed and direction of winds, and frequency of storm events and other disturbances. Some of these factors can be greatly influenced by human actions. For example, when the local vegetation is disturbed, its moderating influence on erosion is reduced or eliminated. In fact, human activities associated with agriculture, forestry, and road-building have greatly increased the rates of erosion in almost all regions of the world. In many cases, the increased losses of soil have had serious consequences for the productivity of agricultural land and for natural biodiversity (see Chapters 14, 20, 23, and 24).

Rocks, sand, clays, and other debris eroded from mountains and other uplands must, of course, go somewhere. These materials are carried to lower altitude, and eventually much of the mass is deposited in the oceans, where they settle to the bottom in a process

known as sedimentation. Over extremely long periods of time (tens or more millions of years), the mass of sedimented material builds up to the extent that intense pressure is exerted on lower levels of the sediment, which causes it to become more densely packed and fuse into sedimentary rock in a process called lithification. Examples of sedimentary rocks are mudstone, sandstone, shale, limestone, and mixtures of these known as conglomerates (the latter may also contain eroded non-sedimentary rocks, such as granite and basalt).

Eventually, under the influence of tectonic forces, enormously slow and powerful collisions of crustal plates can cause areas of deep-oceanic sedimentary rocks to uplift, sometimes raising them to great altitude and contributing to the formation of new mountain ranges underwater or on the continents. As such, geological uplift is the means by which marine rocks and fossils find their way to the tops of the highest mountains. Uplift and mountain building are important stages in the geological recycling of some of the continental mass that was wasted downslope during millions of years of erosion.

The Hydrosphere

The hydrosphere is the portion of Earth that contains water (H_2O), including in the oceans, atmosphere, land surface, and underground. The hydrologic cycle (or water cycle) refers to the rates of movement (fluxes) of water among these various reservoirs (compartments). The hydrologic cycle functions at all scales, ranging from local to global. The major elements of the global hydrologic cycle are illustrated in Figure 3.2.

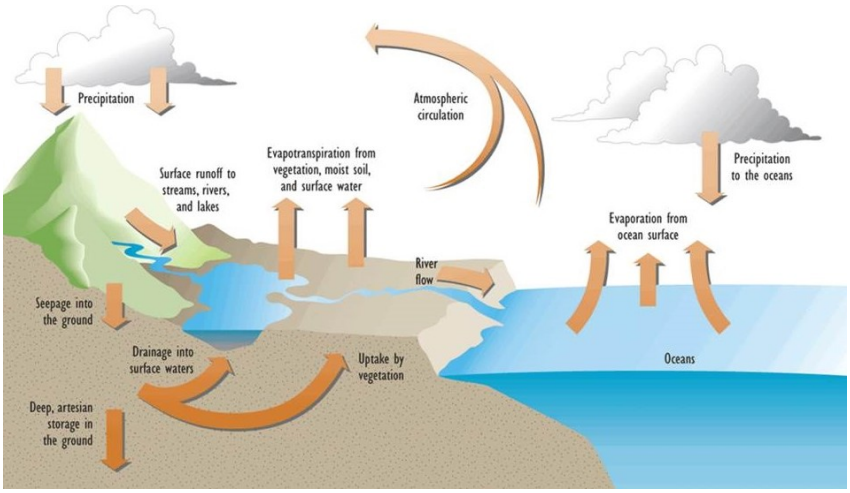


Figure 3.2. Major Elements of the Hydrologic Cycle. The hydrologic cycle includes the influences of oceans and other kinds of surface water (such as lakes and rivers), as well as groundwater and atmospheric moisture (occurring as clouds and humidity). Water evaporates, precipitates as rain and snow, and flows in various kinds of channels, both along the surface as well as underground.

Each compartment of the hydrologic cycle has both input and output fluxes, and the sum of all of these elements comprises the cycle. If the rate of input to a compartment equals the rate of output, then there is a flow-through equilibrium and the amount of water present does not change. Of course, if input exceeds output, the compartment increases in size over time, and it decreases if input is less than output.

On the global scale, the major compartments of the hydrologic cycle are in a long-term equilibrium condition. However, this is not generally true on a local scale, especially over shorter intervals of time. For example, a particular area may temporarily flood or dry out. In addition, local hydrological conditions can change over the long term. Glaciation, for example, stores immense quantities of solid water on land, and excessive use of groundwater can deplete an artesian reservoir (aquifer).



Image 3.4. The global hydrologic cycle involves water movement through the atmosphere, on the surface, and underground, as well as storage in oceans, lakes, glaciers, and groundwater. Ultimately, rivers like the Niagara River, which flows north from Lake Erie to Lake Ontario, represent a flow to the ocean of water that had been deposited to the landscape as rain or snow. Niagara Falls is located on the Niagara River. Source: B. Freedman

Although the hydrologic cycle is an exceedingly complex phenomenon, it can be examined in the context of four major compartments (Table 3.2):

1. The oceans are the largest hydrological compartment, accounting for about 97.4% of all water on the planet.
2. Surface waters occur on the landmasses and account for 2.3% of global water. Almost all that amount is tied up in glaciers, mostly in Antarctica and Greenland, with lakes, ponds, rivers, streams, and other surface bodies of liquid water amounting to only 0.002%.
3. Groundwater accounts for 0.32% of global water. Groundwater can occur in relatively shallow soil horizons, where it is accessible for uptake by plants, or it can drain laterally into surface waters such as lakes and streams. Deeper groundwater is inaccessible for these purposes and it forms artesian reservoirs in spaces within porous or fractured bedrock. Such aquifers receive water infiltrating by deep drainage from above or by long-distance underground transport from nearby upland areas.
4. Atmospheric water accounts for only about 0.001% of the global total. It can occur as a gas, vapor (tiny, suspended droplets), or solid (ice crystals), all of which are highly variable over space and time. A cloud is a dense aggregation of liquid or solid water in the atmosphere, while gaseous water is invisible. Note that the maximum amount of water a volume of atmosphere can hold is highly dependent on temperature, with warmer air having a much greater water-storage capacity than cold air. The term humidity refers to the actual concentration of water in the atmosphere (measured in g/m3), while relative humidity expresses actual humidity as a percentage of the saturation value for a particular temperature.

Compartments	Quantity (10^{14} t)	Percent of Total
oceans	12300	97.4
glaciers	286	2.3
groundwater (to 0.8 km)	40	0.32
inland waters	0.25	0.002
atmosphere	0.13	0.001
Fluxes	**Quantity (10^{14} t/y)**	
evaporation:	4.4	
from oceans	3.8	
from land surfaces	0.6	
total precipitation:	4.4	
to oceans	1	
to land surfaces	4.4	
atmospheric transfer oceans to land	0.4	
surface runoff from land	0.2	

Table 3.2. The Hydrologic Cycle. This table shows the quantity of water involved in various global compartments and fluxes. Source of data: Botkin and Keller (2014).

Evaporation is a change of state of water from a liquid to a gas, or from a solid directly to a gas (evaporation directly from ice or snow is more properly referred to as sublimation). Globally, about 86% of evaporation is from the oceans, and the rest is from terrestrial surfaces. On terrestrial landscapes, water can evaporate from bodies of surface water, from moist soil and rocks, and from vegetation. Transpiration refers specifically to the evaporation of water from plants, while evapotranspiration refers to all sources of evaporation from a landscape.

Precipitation is the deposition of water from the atmosphere, occurring as liquid rain or as solid snow or hail. In addition, vapor-phase atmospheric water can condense or freeze onto surfaces as dew or frost, respectively. As previously noted, most global evaporation is from the oceans, much of which precipitates back to them. However, some is transported by moving air masses over the continents, resulting in a net import of evaporated water from the oceans to the land surfaces. Precipitation volumes can be especially large in mountainous areas facing an ocean, a phenomenon known as orographic precipitation (In Detail 3.1).

Surface flows involve water that is transported in streams and rivers. In contrast, lakes and ponds are relatively static storage reservoirs. Surface flows move in response to gravitational descents associated with altitude – in other words, water flows downhill. Ultimately, most surface flows carry water to the oceans, thereby helping to balance the net import of moisture evaporated from the oceans.

In Detail 3.1: Orographic Precipitation along a Transect through Coastal British Columbia

The spatial pattern of precipitation in coastal British Columbia illustrates the phenomenon of orographic precipitation. It occurs as moisture-laden air masses, blown by the prevailing westerly winds from the Pacific Ocean, encounter the mountains of the Coast Range. As the air masses rise, they cool (by 0.5 to 0.8°C for every 100 m increase in elevation), which greatly reduces their ability to hold water. This causes much of the moisture to condense into clouds and to then precipitate from the atmosphere as snow and rain.

As the air mass passes to the other side of the mountains and starts to descend, it warms again, which increases its moisture-holding capacity. Therefore, precipitation is much sparser on the rain-shadow side of the mountains.

Consequently, coastal Vancouver has much more rainfall (about 110 cm/y) than Penticton in the inland Okanagan Valley (28 cm/y). However, local orographgic effects are also considerable in the Greater Vancouver area, where rainfall is only about 50 cm/y in the southern suburbs of Delta, but as much as 250 cm/y in places nearer the mountains, such as North Vancouver.

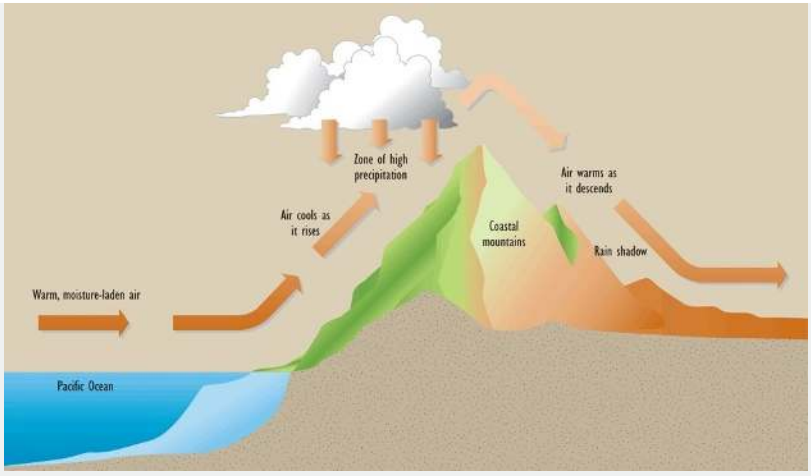


Figure 3.3. A diagrammatic model of orographic precipitation.

Groundwater drainage involves the infiltration of water into the ground. Shallow groundwater can move laterally, eventually draining into surface waters. It can also be taken up by plant roots to later be transpired into the atmosphere through foliage. However, deeper groundwater is not available for plant uptake or to recharge surface waters. It accumulates in underground artesian reservoirs, which can be very large. The biggest such aquifer in North America is the Ogallala, which underlies about 450,000 km² of the western U.S.

The hydrologic cycle is extremely important. Water is needed by natural ecosystems for the metabolic needs of organisms, for cooling, and as a ubiquitous solvent that allows water-soluble nutrients to be absorbed by organisms. Water is also required by people for use in agriculture, industry, and recreation. Unfortunately, in many regions water and its biological resources (such as fish) have been used excessively, and water quality has been degraded through pollution. Damages caused to water and its resources, and ways of mitigating those effects, are common themes in many chapters in this book.

The Atmosphere

The atmosphere is an envelope of gases that surrounds the Earth and is held in place by the attractive forces of gravity. The density of the atmospheric mass is much greater close to the surface and decreases rapidly with increasing altitude. The atmosphere consists of four layers, the boundaries of which are inexact because they may vary over time and space:

1. The troposphere (or lower atmosphere) contains 85-90% of the atmospheric mass and extends from the surface to an altitude of 8-20 km. It is thinner at high latitudes, and thicker at equatorial latitudes, but also varies seasonally, at any place being thicker during the summer than in the winter. It is typical for air temperature to decrease with increasing altitude within the troposphere, and convective air currents (winds) are common. Consequently, the troposphere is sometimes referred to as the "weather layer."
2. The stratosphere extends from the troposphere to as high as about 50 km, depending on the season and latitude. Air temperature varies little with altitude within the stratosphere, and there are few convective air currents.
3. The mesosphere extends beyond the stratosphere to about 75 km.
4. The thermosphere extends to 450 km or more.



Image 3.5. The atmosphere is composed of a mixture of gases, fine particulates, and water vapor occurring as clouds. This view of a foggy tropical forest was taken in the highlands of Peru. Source: B. Freedman

Beyond the atmosphere is outer space, an immeasurably vast region where the Earth exerts no detectable chemical or thermal influences.

About 78% of the mass of the atmosphere is composed of nitrogen gas (N_2), while 21% is oxygen (O_2), 0.9% argon (Ar), and 0.04% carbon dioxide (CO_2). The rest is various trace gases, including potentially toxic ones such as ozone (O_3) and sulphur dioxide (SO_2) (see Chapter 16). The atmosphere also contains highly variable concentrations of water vapor, which can range from only 0.01% in frigid winter air in the Arctic to 5% in warm, humid, tropical air. On average, the total weight of the atmospheric mass exerts a pressure at sea level of around 1.0×10^5 pascals (Pa; or one atmosphere), which is equivalent to 1.0 kg per cm^2.

The atmosphere is a highly dynamic medium, being variable over space and time. This is particularly true of the troposphere, within which gradients of temperature and energy are most pronounced. To even out the energy gradients, there is a streaming of atmospheric mass from regions of relatively high pressure to those with lower pressure. These more-or-less lateral atmospheric movements are known as wind. The vigour and speed of winds can range from barely perceptible to several hundred kilometres per hour in extremely turbulent, rotating air masses such as a tornado or hurricane. In general, winds are caused when air heated by the sun becomes less dense and rises in altitude, to be replaced at the surface by an inflow of cooler, denser air from elsewhere. Simply interpreted, this movement of atmospheric mass represents an enormous gaseous convective cell. These atmospheric movements occur on both local and global scales and are extremely variable over space and time. At the global level, however, a broad general pattern of circulation is discernible.

As was noted above, wind directions are influenced by the relative locations of high and low atmospheric pressures. Wind directions are also influenced by the Coriolis effect, which is caused by the west-to-east rotation of Earth. For example, in the mid-latitudes of the Northern Hemisphere, the distribution of pressure in the lower atmosphere provides a northward force on wind direction. The Coriolis force, which deflects motions to the right in that hemisphere, balances the pressure-gradient force so that the winds tend to blow from west to east. In comparison, in the mid-latitudes of the Southern Hemisphere, the pressure gradient force is directed toward the south, while the Coriolis force deflects motions to the left. On balance, this again results in winds tending to blow from west to east. Local patterns of wind flow are also influenced by surface topography—mountains are barriers that deflect winds upward or around, while valleys can channel wind flows.

Prevailing winds blow relatively continuously in a dominant direction. There are three major classes of prevailing winds:

1. trade winds are tropical airflows that blow from the northeast (to the southwest) in the Northern Hemisphere, and from the southeast in the Southern Hemisphere
2. westerlies are mid-latitude winds that blow from the southwest in the Northern Hemisphere, and from the northwest in the Southern Hemisphere
3. polar easterlies blow from the northeast at high northern latitudes, and from the southeast near Antarctica.

Climate and Weather

Climate refers to the prevailing atmospheric conditions of temperature, precipitation, humidity, wind speed and direction (together, these are wind velocity), insolation (incoming solar radiation), visibility, fog, and cloud cover in a place or region. Climatic data are usually calculated as statistics (such as averages or ranges of values), using data obtained from at least several decades of monitoring (the preferred period for the calculation of "normal" climatic parameters is at least 30 years).

In contrast, weather refers to day-to-day or instantaneous meteorological conditions (the latter is referred to as "real-time" weather). Because weather is related to short-term conditions, it is much more variable over time and space than climate. Most aspects of climate are functions of solar insolation and of how this incoming energy is absorbed, reflected, and re-radiated by the atmosphere, oceans, and terrestrial surfaces. The complex subject of physical energy budgets is described in Chapter 4. For the present purpose, it is worthwhile to examine several ecologically important aspects:

- **Give Thanks to the Sun.** If it were not for the warming influence of solar radiation, the temperature of the surface and atmosphere would approach the coldest that is physically possible – this is absolute zero, or -273°C (or 0o on the Kelvin scale). Although Earth has a limited ability to generate its own heat by the decay of radioactive elements in its core, this is insufficient to provide much warming at the surface. Therefore, solar energy is critical to maintaining the surface temperature within a range that organisms can tolerate.
- **Atmospheric Reflection and Absorption.** Conditions in the atmosphere have a great influence on climatic factors. For instance, cloud cover and tiny particulates are highly reflective of many visible wavelengths of solar radiation and so have a marked cooling effect on the lower atmosphere and the surface. In addition, the atmosphere contains trace concentrations of certain gases that absorb some of the infrared radiation that the planet emits to cool itself of the heat obtained by absorbing solar radiation. The most important of these so-called "greenhouse gases" are water vapor, carbon dioxide, and methane. This influence is called the greenhouse effect, and it maintains the surface temperature of Earth at an average of about 15°C, or 33°C warmer than the -18°C it would be without this moderating effect (see Chapters 4 and 17).
- **Night and Day.** At any place on the surface, the input of solar radiation is high during the day and low at night. (At night, the only radiation inputs are from distant stars and from solar radiation reflected by atmospheric particulates and the moon—these sparse inputs are known as "skylight.") The daily, 24-hour (diurnal) variations in energy input result in large changes in weather. However, this effect varies greatly between tropical and polar latitudes. Tropical regions have approximately equal day and night lengths of about 12 hours each, which do not vary much during the year. In contrast, polar latitudes are much more seasonal, with almost continuous light during much of the summer, and constant night during part of the winter. Temperate latitudes are intermediate, with longer day lengths during the summer and shorter ones during winter.
- **Effects of Latitude.** Places at tropical latitudes tend to face incoming solar radiation on a relatively perpendicular angle (closer to 90° at noon). Polar latitudes have a more oblique angle of solar incidence, and temperate latitudes are intermediate in this regard. The more perpendicular the angle of incidence of solar radiation is, the smaller the surface area over which the incoming energy is distributed and the more intense the resulting heating. The angle of solar incidence has a strong influence on the amounts of unit-area solar radiation that are received at various latitudes, and is a major reason (along with seasonality) why the tropics are warmer than polar regions.
- **Seasons.** Earth's axis tilts at a 23.5° angle relative to the incidence of solar radiation. Consequently, during the planet's annual revolution around the Sun, there are seasonal differences in energy received between the Northern and Southern Hemispheres. In the Northern Hemisphere, the angle of incidence is closer to perpendicular from March 21 to September 22, giving relatively warmer conditions, while the angle is more oblique from September 22 to March 21, resulting in cooler conditions. These seasons are reversed in the Southern Hemisphere. Because Earth's orbit is elliptical, climatic seasons are also influenced by the varying distance from the Sun. However, this effect is relatively small compared with that of the inclination of the axis.
- **Aspect.** On a local scale, the direction that a slope faces (known as its aspect) has a substantial influence on the amount of solar radiation received. In the Northern Hemisphere, south-facing, and to a lesser degree west-facing slopes are relatively warm, while north- and east-facing slopes are cooler. In the Southern Hemisphere, north-facing slopes are warmer.
- **Slope.** The degree of slope, or the angle of inclination of the land, also affects the amount of energy received. The closer the slope approximates a perpendicular angle to incoming solar radiation, the greater is the energy input per unit of surface area. In the Northern Hemisphere, this effect is greatest on south-facing slopes.
- **Soil and Vegetation Cover.** Darker surfaces absorb much more solar radiation than do lighter surfaces. This is the reason why a black asphalt surface gets much hotter during the day than one made of light-coloured cement. Plant canopies also vary in their

absorption and reflection characteristics, depending on the colour of the foliage and the angle at which it is oriented to incoming solar radiation. Major changes in the character of vegetation, as occur when forest is converted into agricultural or urban land-use, can affect local, and sometimes regional, weather and climate.

- **Snow and Ice Cover.** Because snow and ice are highly reflective of solar radiation, surfaces covered by those materials absorb relatively little insolation. The melting of snow cover in the springtime exposes a much more absorptive ground surface, and warming then accelerates.
- **Evaporation of Water.** Moist surfaces are cooled by the evaporation of water, a process that absorbs thermal energy. Therefore, the transpiration of water from plant foliage has a cooling effect, similar to the evaporation of sweat from the body surface of a human.

The above factors influence the input, reflection, absorption, and dissipation of solar radiation, resulting in large variations of air, water, and surface temperatures over the surface of Earth. The energy gradients that develop result in global processes that attempt to distribute the energy more evenly, by movements of air masses in the atmosphere (winds) and currents of water in the oceans. In addition, prevailing wind directions can interact with oceanic currents to generate circular water flows known as gyres. Subtropical gyres rotate clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere, while subpolar gyres rotate in the opposite directions.

Climate has an important influence on the character of ecological development in any region or place. Climatic conditions can vary on a large scale, called macroclimate, which affects the nature of ecosystems over a large area. Climatic conditions can also vary on much smaller scales, called microclimate, which may be affected by local topography, proximity to the ocean or a large lake, or understorey conditions beneath a dense canopy of tree foliage. Four climatic factors particularly affect the development of ecosystems (see Chapter 8). Of these, variations of precipitation and temperature generally have the greatest influence. The amounts of precipitation are greatly affected by the flow of prevailing winds, the humidity of air masses, and the influence of topography (see In Detail 3.1). A dry climate may only support desert vegetation, whereas wetter conditions may allow old-growth forest and wetlands to develop.

Temperature is relatively warm in tropical latitudes and at lower altitude in mountainous terrain, while it is cooler at high latitude and high altitude. In general, places with cold temperatures develop tundra vegetation, whereas warmer temperatures may support forest. Temperate and polar latitudes have large seasonal fluctuations in temperature. Tropical forest develops in moist regions where temperature remains uniformly warm, while temperate and boreal forests are dominated by tree species that can tolerate cold temperatures during the winter. Wind can also have a substantial ecological influence, although this is typically less important than that of precipitation and temperature. Very windy locations may not be able to support forest, even though precipitation and temperature are otherwise favourable. This occurs in many coastal habitats in Canada, where windy conditions result in shrub-dominated ecosystems rather than the forest that occurs farther inland.

Extreme events of weather, such as drought, flooding, a hurricane, or a tornado, can also be important. Severe disturbances have a large influence on ecological development, especially where they occur frequently. For example, frequent drought or severe windstorms may restrict the development of forest in some regions, even though the average climatic conditions may be favourable.

Major elements of the climates of Canada are described in Canadian Focus 3.1. Their relationship with ecological development is examined in Chapter 8.

Canadian Focus 3.1. Climates of Canada

Canada is a huge country, the second largest in the world after Russia. The wide range of latitude means that local and regional climates vary from cold polar in the High Arctic to warm temperate in southern Ontario and southern British Columbia. Canada also has extremely varied topography, with extensive low regions and many areas at high elevation, particularly in the mountains of Labrador, the eastern Arctic Islands, and the Rocky Mountains. Therefore, the regions of Canada are characterized by huge differences in climate.

The figure shows seasonal patterns of change, using temperature as an indicator. Note that the high-Arctic station at Alert (82° N) on far-northern Ellesmere Island is much colder and has a brief growing season compared with the southerly stations. Thompson (55° N) is in the boreal zone of northern Manitoba and it also has a relatively cold climate with a short growing season. Lethbridge,

in the prairie region of southern Alberta, has a temperate prairie climate with a relatively warm and extended growing season. Windsor (42° N) is the most southern location shown, and it has the warmest climate and longest growing season.

	St. John's, NL	Halifax, NS	Montreal, QC	Toronto, ON	Winnipeg, MB	Regina, SK	Edmonton, AB	Penticton, BC	Vancouver, BC	Iqaluit, NU
Temperature (°C)										
Annual average	5	6.6	6.8	8.2	3	3.1	2.6	9.5	10.4	-9.3
Days >20° C	53	89	117	122	110	108	87	129	77	44
Days <-10° C	35	45	63	39	102	102	99	11	2	182
Days frost-free	139	163	165	168	121	115	110	159	237	74
Growing Degree-Days										
days >10 °C	559	922	1260	1325	1018	913	611	1234	966	24
Precipitation (cm/y)										
Annual total	154	141	100	79	52	39	45	29	119	40
As rain	121	119	79	68	42	31	34	22	115	20
As snow	33	22	21	11	10	8	9	7	4	20
Days rainy	163	128	119	113	78	72	77	99	165	52
Days snowy	79	58	59	45	54	56	53	26	9	114
Wind (kph)										
Average wind	21.9	16.5	14.4	15	17.1	18.4	12.2	10.9	12.2	15.7
Days wind >63	16	3	<1	6	1	9	0	<1	2	10

Table 3.3 Normal climate values (longer-term averages) calculated for the period 1981 to 2010 (Environment Canada, 2015).

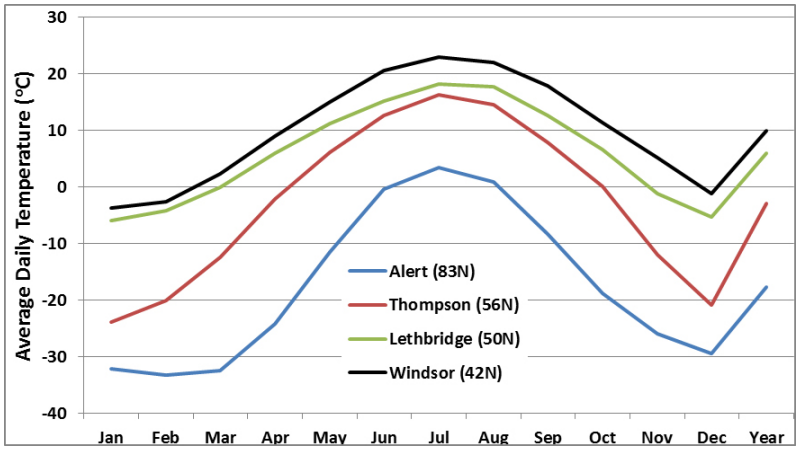


Figure 3.4. Average daily temperature for a range of places in Canada. Source: Data from Environment Canada (2015).

Conclusions

Knowledge of the physical world is a central aspect of environmental science – it provides essential context for understanding the causes and consequences of almost all changes that are caused by human activities. The physical and structural attributes of Earth influence the geological and geographical forces affecting its surface (both water and land) and atmosphere. In addition, the amount and spectral quality of incoming sunlight have a profound influence on the energy budget and climates of the planet. Increasingly, anthropogenic influences are having a large, cumulative effect on these natural effects and are transforming the surface attributes of Earth by affecting erosion, surface cover, environmental chemistry, and even global climate.

Questions for Review

1. What are the various layers of Earth's solid sphere and atmosphere? Briefly describe the characteristics of these layers.
2. What causes tectonic forces, and what are their consequences on crustal dynamics?
3. What is glaciation? Describe the major surface features that it leaves behind.
4. What are key factors affecting regional climate and microclimate?

Questions for Discussion

1. Explain how geological forces have influenced landscape features in the region where you live.
2. Where does your drinking water come from? Trace its origins and disposal in terms of the hydrologic cycle.

3. Explain the differences between climate and weather. Discuss the influences of climate and weather on your daily and annual life.
4. Natural disasters, such as extreme weather caused by a windstorm or massive rain event, are rare but inevitable occurrences. What is the recent history of natural disasters in the place where you live? Do you think that land-use and other human influences may have increased the possibility of worse damage being caused by these unpredictable events?

Exploring Issues

1. You are part of a research team that is investigating the potential environmental effects of climate change in a region of hilly topography. Your responsibility is to characterize the climatic conditions in the study area, giving sufficient detail so the team can understand the overall conditions as well as the local ones, such as in valleys, on slopes, and on hilltops. What kinds of factors would you have to consider when designing the climate-monitoring program? Consider the following aspects: (a) the number of monitoring sites, (b) where monitoring sites should be located, (c) what variables to measure (such as wind, temperature, precipitation, sunlight), and (d) how long you must monitor conditions before determining the normal climate (as opposed to the weather).

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CHAPTER OVERVIEW

3: Matter, Energy, and Life

Learning Outcomes

After studying this chapter, you should be able to:

- Describe matter and elements
- Describe the ways in which carbon is critical to life
- Describe the roles of cells in organisms
- Compare and contrast prokaryotic cells and eukaryotic cells
- Summarize the process of photosynthesis and explain its relevance to other living things

Page 3.1: Matter

Page 3.2: Energy

Page 3.3: A Cell is the Smallest Unit of Life

Page 3.4: Energy Enters Ecosystems Through Photosynthesis

Page 3.5: Energy Flow through Ecosystems

Page 3.6: Biogeochemical Cycles

Page 3.S: Matter, Energy, and Life (Summary)

Thumbnail image - This sage thrasher's diet, like that of almost all organisms, depends on photosynthesis.

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Page 3.1: Matter

Atoms, Molecules, & Compounds

At its most fundamental level, life is made of **matter**. Matter is something that occupies space and has mass. All matter is composed of **elements**, substances that cannot be broken down or transformed chemically into other substances. Each element is made of atoms, each with a constant number of protons and unique properties. A total of 118 elements have been defined; however, only 92 occur naturally and fewer than 30 are found in living cells. The remaining 26 elements are unstable and therefore do not exist for very long or are theoretical and have yet to be detected. Each element is designated by its chemical symbol (such as H, N, O, C, and Na), and possesses unique properties. These unique properties allow elements to combine and to bond with each other in specific ways.

An **atom** is the smallest component of an element that retains all of the chemical properties of that element. For example, one hydrogen atom has all of the properties of the element hydrogen, such as it exists as a gas at room temperature and it bonds with oxygen to create a water molecule. Hydrogen atoms cannot be broken down into anything smaller while still retaining the properties of hydrogen. If a hydrogen atom were broken down into subatomic particles, it would no longer have the properties of hydrogen. At the most basic level, all organisms are made of a combination of elements. They contain atoms that combine together to form molecules. In multicellular organisms, such as animals, molecules can interact to form cells that combine to form tissues, which make up organs. These combinations continue until entire multicellular organisms are formed.

All matter, whether it be a rock or an organism, is made of atoms. Often, these atoms combine to form **molecules**. Molecule are chemicals made from two or more atoms bonded together. Some molecules are very simple, like O2, which is comprised of just two oxygen atoms. Some molecules used by organisms, such as DNA, are made of many millions of atoms. All atoms contain protons, electrons, and neutrons (Figure $Page3.1.1$ below). The only exception is hydrogen (H), which is made of one proton and one electron. A **proton** is a positively charged particle that resides in the nucleus (the core of the atom) of an atom and has a mass of 1 and a charge of +1. An **electron** is a negatively charged particle that travels in the space around the nucleus. In other words, it resides outside of the nucleus. It has a negligible mass and has a charge of –1. **Neutrons**, like protons, reside in the nucleus of an atom. They have a mass of 1 and no charge. The positive (protons) and negative (electrons) charges balance each other in a neutral atom, which has a net zero charge.

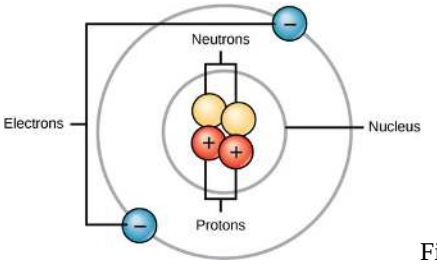


Figure $Page3.1.1$. Atoms are comprised of protons and neutrons located within the nucleus, and electrons surrounding the nucleus. The nucleus of an atom should not be confused with the nucleus of a cell.

Each element contains a different number of protons and neutrons, giving it its own atomic number and mass number. The **atomic number** of an element is equal to the number of protons that element contains. The **mass number** is the number of protons plus the number of neutrons of that element. Therefore, it is possible to determine the number of neutrons by subtracting the atomic number from the mass number.

Isotopes are different forms of the same element that have the same number of protons, but a different number of neutrons. Some elements, such as carbon, potassium, and uranium, have naturally occurring isotopes. Carbon 12, the most common isotope of carbon, contains six protons and six neutrons. Therefore, it has a mass number of 12 (six protons and six neutrons) and an atomic number of 6 (which makes it carbon). Carbon 14 contains six protons and eight neutrons. Therefore, it has a mass number of 14 (six protons and eight neutrons) and an atomic number of 6, meaning it is still the element carbon. These two alternate forms of carbon are isotopes. Some isotopes are unstable and will lose protons, other subatomic particles, or energy to form more stable elements. These are called **radioactive isotopes** or radioisotopes.

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EVOLUTION IN ACTION: Carbon dating

Carbon-14 (14C) is a naturally occurring radioisotope that is created in the atmosphere by cosmic rays. This is a continuous process, so more 14C is always being created. As a living organism develops, the relative level of 14C in its body is equal to the concentration of 14C in the atmosphere. When an organism dies, it is no longer ingesting 14C, so the ratio will decline. 14C decays to 14N by a process called beta decay; it gives off energy in this slow process. After approximately 5,730 years, only one-half of the starting concentration of 14C will have been converted to 14N. The time it takes for half of the original concentration of an isotope to decay to its more stable form is called its half-life.

Because the half-life of 14C is long, it is used to age formerly living objects, such as fossils. Using the ratio of the 14C concentration found in an object to the amount of 14C detected in the atmosphere, the amount of the isotope that has not yet decayed can be determined. Based on this amount, the age of the fossil can be calculated to about 50,000 years (Figure $Page3.1.2$ below). Isotopes with longer half-lives, such as potassium-40, are used to calculate the ages of older fossils. Through the use of carbon dating, scientists can reconstruct the ecology and biogeography of organisms living within the past 50,000 years.



Figure $Page3.1.2$. The age of remains that contain carbon and are less than about 50,000 years old, such as this pygmy mammoth, can be determined using carbon dating. (credit: Bill Faulkner/ NPS)

Chemical Bonds

How elements interact with one another depends on the number of electrons and how they are arranged. When an atom does not contain equal numbers of protons and electrons it is called an **ion**. Because the number of electrons does not equal the number of protons, each ion has a net **charge**. For example, if sodium loses an electron, it now has 11 protons and only 10 electrons, leaving it with an overall charge of +1. Positive ions are formed by losing electrons and are called **cations**. Negative ions are formed by gaining electrons and are called **anions**. Elemental anionic names are changed to end in -ide. As an example, when chlorine becomes an ion it is referred to as chloride.

Ionic and covalent bondsare strong bonds formed between two atoms. These bonds hold atoms together in a relatively stable state. **Ionic bonds** are formed between two oppositely charged ions (an anion and a cation). Because positive and negative charges attract, these ions are held together much like two oppositely charged magnets would stick together. **Covalent bonds** form when electrons are shared between two atoms. Each atom shares one of their electrons, which then orbits the nuclei of both atoms, holding the two atoms together. Covalent bonds are the strongest and most common form of chemical bond in organisms. Unlike most ionic bonds, covalent bonds do not dissociate in water.

Covalent bonds come in two varieties: polar and non-polar. A **non-polar covalent bond** occurs when electrons are shared equally between the two atoms. **Polar covalent bonds** form when the electrons are shared unequally. Why does this occur? Each element has a known **electronegativity**: a measure of their affinity for electrons. Some elements, such as oxygen, are very electronegative because they strongly attract electrons from other atoms. Hydrogen, meanwhile, has low electronegativity and thus weakly attracts electrons, in comparison. Polar covalent bonds form when the two atoms involved have significantly different electronegativities.

In biological systems, this occurs when oxygen bonds with hydrogen and when nitrogen (also quite electronegative) bonds with hydrogen.

When oxygen and hydrogen bond, for example, the shared electrons are pulled more strongly toward oxygen and thus farther away from hydrogen's nucleus. Because the electrons move farther away from hydrogen, it becomes slightly positively charged (δ+). The oxygen becomes slightly negatively charged as the electrons become closer to it (δ–). If two molecules with polar covalent bonds approach one another, they can interact due to the attraction of opposite electrical charges. For example, the slight positive charge of hydrogen in a water molecule can be attracted to the slight negative charge of oxygen in a different water molecule (Figure $Page3.1.3$). This interaction between two polar molecules is called a **hydrogen bond**. This type of bond is very common in organisms. Notably, hydrogen bonds give water the unique properties that sustain life. If it were not for hydrogen bonding, water would be a gas rather than a liquid at room temperature.

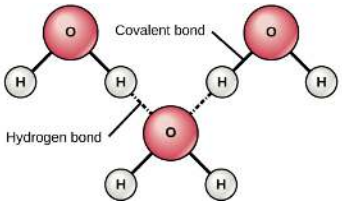


Figure $Page3.1.3$. Hydrogen bonds form between slightly positive (δ+) and slightly negative (δ–) charges of polar covalent molecules, such as water.

WATER IS CRUCIAL TO MAINTAINING LIFE

Do you ever wonder why scientists spend time looking for water on other planets? It is because water is essential to life; even minute traces of it on another planet can indicate that life could or did exist on that planet. Water is one of the more abundant molecules in living cells and the one most critical to life as we know it. Approximately 60–70 percent of your body is made up of water. Without it, life simply would not exist.

- **Water is polar.** The hydrogen and oxygen atoms within water molecules form polar covalent bonds. The shared electrons spend more time associated with the oxygen atom than they do with hydrogen atoms. There is no overall charge to a water molecule, but there is a slight positive charge on each hydrogen atom and a slight negative charge on the oxygen atom. Because of these charges, the slightly positive hydrogen atoms repel each other and form the unique shape. Each water molecule attracts other water molecules because of the positive and negative charges in the different parts of the molecule. Water also attracts other polar molecules (such as sugars) that can dissolve in water and are referred to as hydrophilic ("water-loving").
- **Water stabilizes temperature.** The hydrogen bonds in water allow it to absorb and release heat energy more slowly than many other substances. Temperature is a measure of the motion (kinetic energy) of molecules. As the motion increases, energy is higher and thus temperature is higher. Water absorbs a great deal of energy before its temperature rises. Increased energy disrupts the hydrogen bonds between water molecules. Because these bonds can be created and disrupted rapidly, water absorbs an increase in energy and temperature changes only minimally. This means that water moderates temperature changes within organisms and in their environments.
- **Water is an excellent solvent.** Because water is polar, with slight positive and negative charges, ionic compounds and polar molecules can readily dissolve in it. Water is, therefore, what is referred to as a solvent—a substance capable of dissolving another substance. The charged particles will form hydrogen bonds with a surrounding layer of water molecules.
- **Water is cohesive.** Have you ever filled up a glass of water to the very top and then slowly added a few more drops? Before it overflows, the water actually forms a dome-like shape above the rim of the glass. This water can stay above the glass because of the property of cohesion. In cohesion, water molecules are attracted to each other (because of hydrogen bonding), keeping the molecules together at the liquid-air (gas) interface, although there is no more room in the glass. Cohesion gives rise to surface tension, the capacity of a substance to withstand rupture when placed under tension or stress. When you drop a small scrap of paper onto a droplet of water, the paper floats on top of the water droplet, although the object is denser (heavier) than the water. This occurs because of the surface tension that is created by the water molecules. Cohesion and surface tension keep the water molecules intact and the item floating on the top. It is even possible to "float" a steel needle on top of a glass of water if you place it gently, without breaking the surface tension. These cohesive forces are also related to the water's property of adhesion, or the attraction between water molecules and other molecules. This is observed when water "climbs" up a straw placed in a glass of water. You will notice that the water appears to be higher on the sides of the straw than in the middle. This is because

the water molecules are attracted to the straw and therefore adhere to it. Cohesive and adhesive forces are important for sustaining life. For example, because of these forces, water can flow up from the roots to the tops of plants to feed the plant.

Buffers, pH, Acids, and Bases

The **pH** of a solution is a measure of its **acidity** or **alkalinity**. The pH scale ranges from 0 to 14. A change of one unit on the pH scale represents a change in the concentration of hydrogen ions by a factor of 10, a change in two units represents a change in the concentration of hydrogen ions by a factor of 100. Thus, small changes in pH represent large changes in the concentrations of hydrogen ions. Pure water is neutral. It is neither acidic nor basic and has a pH of 7.0. Anything below 7.0 (ranging from 0.0 to 6.9) is acidic, and anything above 7.0 (from 7.1 to 14.0) is alkaline. The blood in your veins is slightly alkaline (pH = 7.4). The environment in your stomach is highly acidic (pH = 1 to 2). Orange juice is mildly acidic (pH = approximately 3.5), whereas baking soda is basic (pH = 9.0).

Acids are substances that provide hydrogen ions (H+) and lower pH, whereas **bases** provide hydroxide ions (OH–) and raise pH. The stronger the acid, the more readily it donates H+. For example, hydrochloric acid and lemon juice are very acidic and readily give up H+ when added to water. Conversely, bases are those substances that readily donate OH–. The OH– ions combine with H+ to produce water, which raises a substance's pH. Sodium hydroxide and many household cleaners are very alkaline and give up OH– rapidly when placed in water, thereby raising the pH.

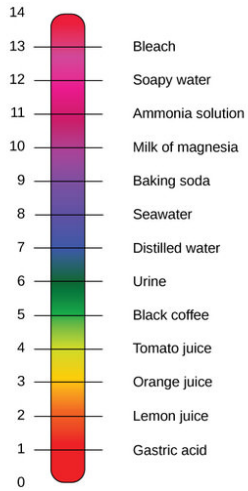


Figure *Page*3.1.4. The pH scale measures the amount of hydrogen ions (H+) in a substance. (credit: modification of work by Edward Stevens)

How is it that we can ingest or inhale acidic or basic substances and not die? **Buffers** are the key. Buffers readily absorb excess H+ or OH–, keeping the pH of the body carefully maintained in the aforementioned narrow range. Carbon dioxide is part of a prominent buffer system in the human body; it keeps the pH within the proper range. This buffer system involves carbonic acid (H_2CO_3) and bicarbonate (HCO_3–) anion. If too much H+ enters the body, bicarbonate will combine with the H+ to create carbonic acid and limit the decrease in pH. Likewise, if too much OH– is introduced into the system, carbonic acid will combine with it to create bicarbonate and limit the increase in pH. While carbonic acid is an important product in this reaction, its presence is fleeting because the carbonic acid is released from the body as carbon dioxide gas each time we breathe. Without this buffer system, the pH in our bodies would fluctuate too much and we would fail to survive.

Biological Molecules

Besides water, the molecules necessary for life are organic. **Organic molecules** are those that contain carbon covalently bonded to hydrogen. In addition, they may contain oxygen, nitrogen, phosphorus, sulfur, and additional elements.There are four major classes of organic molecules: **carbohydrates**, **lipids**, **proteins**, and **nucleic acids.** Each is an important component of the cell and performs a wide array of functions.

It is often said that life is "carbon-based." This means that carbon atoms, bonded to other carbon atoms or other elements, form the fundamental components of many of the molecules found uniquely in living things. Other elements play important roles in biological molecules, but carbon certainly qualifies as the "foundation" element for molecules in living things. It is the bonding properties of carbon atoms that are responsible for its important role.

Carbon can form four covalent bonds with other atoms or molecules. The simplest organic carbon molecule is methane (CH4), in which four hydrogen atoms bind to a carbon atom (Figure $Page 3.1.5$). **Carbohydrates** include what are commonly referred to as simple sugars, like glucose, and complex carbohydrates such as starch. While many types of carbohydrates are used for energy, some are used for structure by most organisms, including plants and animals. For example, cellulose is a complex carbohydrate that adds rigidity and strength to the cell walls of plants. The suffix "-ose" denotes a carbohydrate, but note that not all carbohydrates were given that suffix when names (e.g., starch).

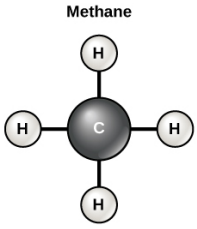


Figure $Page 3.1.5$. Carbon can form four covalent bonds to create an organic molecule. The simplest carbon molecule is methane (CH4), depicted here.

Lipids include a diverse group of compounds that are united by a common feature. Lipids are hydrophobic ("water-fearing"), or insoluble in water, because they are non-polar molecules (molecules that contain non-polar covalent bonds) . Lipids perform many different functions in a cell. Cells store energy for long-term use in the form of lipids called fats. Lipids also provide insulation from the environment for plants and animals. For example, they help keep aquatic birds and mammals dry because of their water-repelling nature. Lipids are also the building blocks of many hormones and are an important constituent of cellular membranes. Lipids include fats, oils, waxes, phospholipids, and steroids.

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. They are all polymers of amino acids. The functions of proteins are very diverse because there are 20 different chemically distinct amino acids that form long chains, and the amino acids can be in any order. Proteins can function as enzymes, hormones, contractile fibers, cytoskeleton rods, and much more. **Enzymes** are vital to life because they act as catalyst in biochemical reactions (like digestion). Each enzyme is specific for the substrate (a reactant that binds to an enzyme) upon which it acts. Enzymes can function to break molecular bonds, to rearrange bonds, or to form new bonds.

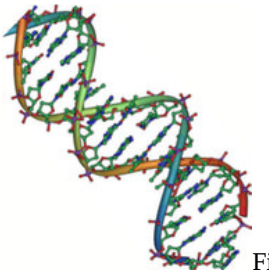


Figure $Page 3.1.6$. The double-helix model shows DNA as two parallel strands of intertwining molecules.

Nucleic acids are very large molecules that are important to the continuity of life. They carry the genetic blueprint of a cell and thus the instructions for its functionality. The two main types of nucleic acids are deoxyribonucleic acid (**DNA**) and ribonucleic acid (RNA). DNA is the genetic material found in all organisms, ranging from single-celled bacteria to multicellular mammals. The other type of nucleic acid, **RNA**, is mostly involved in protein synthesis. The DNA molecules never leave the nucleus, but instead use an RNA intermediary to communicate with the rest of the cell. Other types of RNA are also involved in protein synthesis and its regulation. DNA and RNA are made up of small building blocks known as **nucleotides**. The nucleotides combine with each other to form a polynucleotide: DNA or RNA. Each nucleotide is made up of three components: a nitrogenous base, a pentose (five-carbon) sugar, and a phosphate. DNA has a beautiful double-helical structure (Figure $Page 3.1.6$).

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Additional Resources:

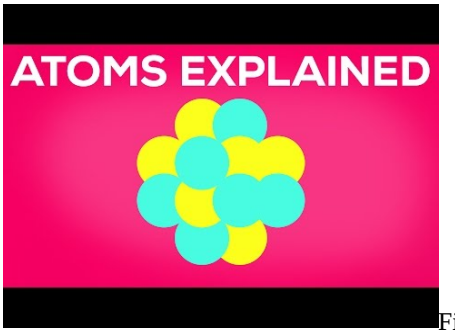


Figure $Page$3.1.8. A video that provides some wicked-awesome information about atoms.

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Page 3.2: Energy

Virtually every task performed by living organisms requires energy. Nutrients and other molecules are imported into the cell to meet these energy demands. For example, energy is required for the synthesis and breakdown of molecules, as well as the transport of molecules into and out of cells. In addition, processes such as ingesting and breaking down food, exporting wastes and toxins, and movement of the cell all require energy.

Scientists use the term **bioenergetics** to describe the concept of energy flow through living systems, such as cells. Cellular processes such as the building and breaking down of complex molecules occur through step-wise chemical reactions. Some of these chemical reactions are spontaneous and release energy, whereas others require energy to proceed. Together, all of the chemical reactions that take place inside cells, including those that consume or generate energy, are referred to as the cell's **metabolism**.

From where, and in what form, does this energy come? How do living cells obtain energy, and how do they use it? This section will discuss different forms of energy and the physical laws that govern energy transfer.

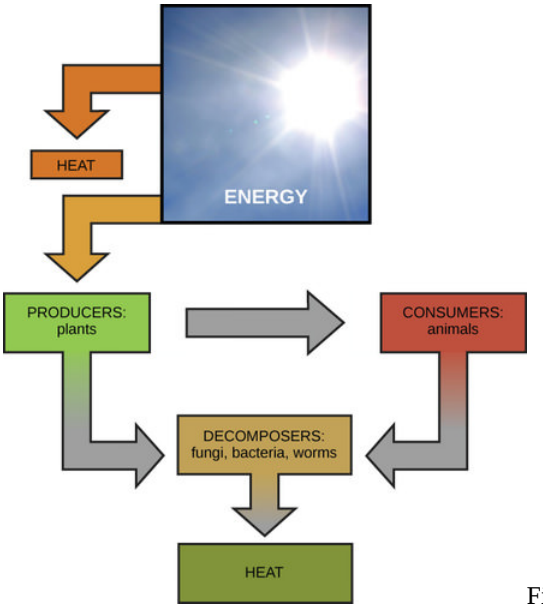


Figure $Page 3.2.1$. Ultimately, most life forms get their energy from the sun. Plants use photosynthesis to capture sunlight, and herbivores eat the plants to obtain energy. Carnivores eat the herbivores, and eventual decomposition of plant and animal material contributes to the nutrient pool.

Energy

Thermodynamics refers to the study of energy and energy transfer involving physical matter. The matter relevant to a particular case of energy transfer is called a system, and everything outside of that matter is called the surroundings. For instance, when heating a pot of water on the stove, the system includes the stove, the pot, and the water. Energy is transferred within the system (between the stove, pot, and water). There are two types of systems: open and closed. In an **open system**, energy can be exchanged with its surroundings. The stovetop system is open because heat can be lost to the air. A **closed system** cannot exchange energy with its surroundings.

Biological organisms are open systems. Energy is exchanged between them and their surroundings as they use energy from the sun to perform photosynthesis or consume energy-storing molecules and release energy to the environment by doing work and releasing heat. Like all things in the physical world, energy is subject to physical laws. The laws of thermodynamics govern the transfer of energy in and among all systems in the universe. In general, **energy** is defined as the ability to do work, or to create some kind of change. Energy exists in different forms: electrical energy, light energy, mechanical energy, and heat energy are all different types of energy. To appreciate the way energy flows into and out of biological systems, it is important to understand two of the physical laws that govern energy.

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The **first law of thermodynamics** states that the total amount of energy in the universe is constant and conserved. In other words, there has always been, and always will be, exactly the same amount of energy in the universe. Energy exists in many different forms. According to the first law of thermodynamics, energy may be transferred from place to place or transformed into different forms, but it cannot be created or destroyed. The transfers and transformations of energy take place around us all the time. Light bulbs transform electrical energy into light and heat energy. Gas stoves transform chemical energy from natural gas into heat energy. Plants perform one of the most biologically useful energy transformations on earth: that of converting the energy of sunlight to chemical energy stored within organic molecules (Figure $Page 3.2.2$ below).

The challenge for all living organisms is to obtain energy from their surroundings in forms that are usable to perform cellular work. Cells have evolved to meet this challenge. Chemical energy stored within organic molecules such as sugars and fats is transferred and transformed through a series of cellular chemical reactions into energy within molecules of ATP (adenosine triphosphate). Energy in ATP molecules is easily accessible to do work. Examples of the types of work that cells need to do include building complex molecules, transporting materials, powering the motion of cilia or flagella, and contracting muscles to create movement.

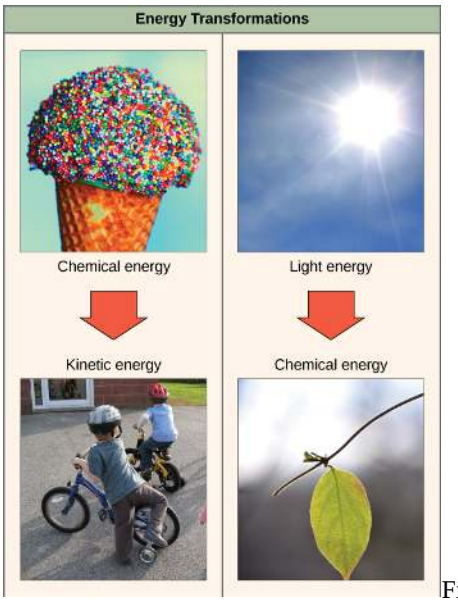


Figure $Page 3.2.2$. Shown are some examples of energy transferred and transformed from one system to another and from one form to another. The food we consume provides our cells with the energy required to carry out bodily functions, just as light energy provides plants with the means to create the chemical energy they need. (credit “ice cream”: modification of work by D. Sharon Pruitt; credit “kids”: modification of work by Max from Providence; credit “leaf”: modification of work by Cory Zanker)

A living cell’s primary tasks of obtaining, transforming, and using energy to do work may seem simple. However, the **second law of thermodynamics** explains why these tasks are harder than they appear. All energy transfers and transformations are never completely efficient. In every energy transfer, some amount of energy is lost in a form that is unusable. In most cases, this form is heat energy.

Thermodynamically, **heat energy** is defined as the energy transferred from one system to another that is not work. For example, when a light bulb is turned on, some of the energy being converted from electrical energy into light energy is lost as heat energy. Likewise, some energy is lost as heat energy during cellular metabolic reactions.

An important concept in physical systems is that of order and disorder. The more energy that is lost by a system to its surroundings, the less ordered and more random the system is. Scientists refer to the measure of randomness or disorder within a system as **entropy**. High entropy means high disorder and low energy. Molecules and chemical reactions have varying entropy as well. For example, entropy increases as molecules at a high concentration in one place diffuse and spread out. The second law of thermodynamics says that energy will always be lost as heat in energy transfers or transformations. Living things are highly ordered, requiring constant energy input to be maintained in a state of low entropy.

Potential and Kinetic Energy

When an object is in motion, there is energy associated with that object. Think of a wrecking ball. Even a slow-moving wrecking ball can do a great deal of damage to other objects. Energy associated with objects in motion is called **kinetic energy**. A speeding bullet, a walking person, and the rapid movement of molecules in the air all have kinetic energy. Now what if that same motionless wrecking ball is lifted two stories above ground with a crane? If the suspended wrecking ball is not moving, is there energy associated with it? The answer is yes. The energy that was required to lift the wrecking ball did not disappear, but is now stored in the wrecking ball by virtue of its position and the force of gravity acting on it. This type of energy is called **potential energy** (Figure $Page 3.2.3$ below). If the ball were to fall, the potential energy would be transformed into kinetic energy until all of the potential energy was exhausted when the ball rested on the ground. Wrecking balls also swing like a pendulum; through the swing, there is a constant change of potential energy (highest at the top of the swing) to kinetic energy (highest at the bottom of the swing). Other examples of potential energy include the energy of water held behind a dam or a person about to skydive out of an airplane.



Figure $Page 3.2.3$. Still water has potential energy; moving water, such as in a waterfall or a rapidly flowing river, has kinetic energy. (credit “dam”: modification of work by “Pascal”/Flickr; credit “waterfall”: modification of work by Frank Gualtieri)

Potential energy is not only associated with the location of matter, but also with the structure of matter. Even a spring on the ground has potential energy if it is compressed; so does a rubber band that is pulled taut. On a molecular level, the bonds that hold the atoms of molecules together exist in a particular structure that has potential energy. The fact that energy can be released by the breakdown of certain chemical bonds implies that those bonds have potential energy. In fact, there is potential energy stored within the bonds of all the food molecules we eat, which is harnessed for use. The type of potential energy that exists within chemical bonds, and is released when those bonds are broken, is called **chemical energy**. Chemical energy is responsible for providing living cells with energy from food. The release of energy occurs when the molecular bonds within food molecules are broken.

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Page 3.3: A Cell is the Smallest Unit of Life

Levels of Biological Organization

Living things are highly organized and structured, following a hierarchy of scale from small to large (Figure $Page3.3.1$). The atom is the smallest and most fundamental unit of matter. It consists of a nucleus surrounded by electrons. Atoms combine to form molecules, which are chemical structures consisting of at least two atoms held together by a chemical bond. In plants, animals, and many other types of organisms, molecules come together in specific ways to create structures called organelles. Organelles are small structures that exist within cells and perform specialized functions. As discussed in more detail below, all living things are made of one or more cells.

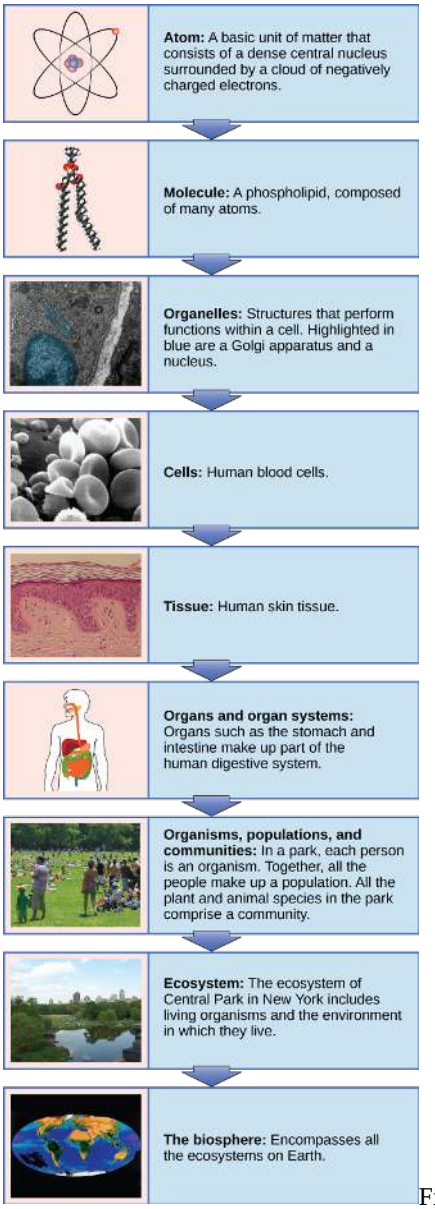


Figure $Page3.3.1$. From an atom to the entire Earth, biology examines all aspects of life. (credit “molecule”: modification of work by Jane Whitney; credit “organelles”: modification of work by Louisa Howard; credit “cells”: modification of work by Bruce Wetzel, Harry Schaefer, National Cancer Institute; credit “tissue”: modification of work by “Kilbad”/Wikimedia Commons; credit “organs”: modification of work by Mariana Ruiz Villareal, Joaquim Alves Gaspar; credit “organisms”: modification of work by Peter Dutton; credit “ecosystem”: modification of work by “gigi4791″/Flickr; credit “biosphere”: modification of work by NASA)

In most multicellular organisms, cells combine to make tissues, which are groups of similar cells carrying out the same function. Organs are collections of tissues grouped together based on a common function. Organs are present not only in animals but also in plants. An organ system is a higher level of organization that consists of functionally related organs. For example vertebrate animals have many organ systems, such as the circulatory system that transports blood throughout the body and to and from the lungs; it includes organs such as the heart and blood vessels. Organisms are individual living entities. For example, each tree in a forest is an organism.

All the individuals of a species living within a specific area are collectively called a population. A community is the set of different populations inhabiting a common area. For instance, all of the trees, flowers, insects, and other populations in a forest form the forest's community. The forest itself is an ecosystem. An ecosystem consists of all the living things in a particular area together with the abiotic, or non-living, parts of that environment such as nitrogen in the soil or rainwater. At the highest level of organization, the biosphere is the collection of all ecosystems, and it represents the zones of life on Earth. It includes land, water, and portions of the atmosphere.

Cell Theory

Close your eyes and picture a brick wall. What is the basic building block of that wall? It is a single brick, of course. Like a brick wall, your body is composed of basic building blocks and the building blocks of your body are cells. Your body has many kinds of cells, each specialized for a specific purpose. Just as a home is made from a variety of building materials, the human body is constructed from many cell types. For example, bone cells help to support and protect the body. Cells of the immune system fight invading bacteria. And red blood cells carry oxygen throughout the body. Each of these cell types plays a vital role during the growth, development, and day-to-day maintenance of the body. In spite of their enormous variety, however, all cells share certain fundamental characteristics.

The microscopes we use today are far more complex than those used in the 1600s by Antony van Leeuwenhoek, a Dutch shopkeeper who had great skill in crafting lenses. Despite the limitations of his now-ancient lenses, van Leeuwenhoek observed the movements of single-celled organism and sperm, which he collectively termed "animalcules." In a 1665 publication called *Micrographia*, experimental scientist Robert Hooke coined the term "cell" (from the Latin *cella*, meaning "small room") for the box-like structures he observed when viewing cork tissue through a lens. In the 1670s, van Leeuwenhoek discovered bacteria and protozoa. Later advances in lenses and microscope construction enabled other scientists to see different components inside cells.

By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the unified **cell theory**, which states that all living things are composed of one or more cells, that the cell is the basic unit of life, and that all new cells arise from existing cells. These principles still stand today. There are many types of cells, and all are grouped into one of two broad categories: prokaryotic and eukaryotic. Animal, plant, fungal, and protist cells are classified as eukaryotic, whereas bacteria and archaea cells are classified as prokaryotic.

All cells share four common components: 1) a plasma membrane, an outer covering that separates the cell's interior from its surrounding environment; 2) cytoplasm, consisting of a jelly-like region within the cell in which other cellular components are found; 3) DNA, the genetic material of the cell; and 4) ribosomes, particles that synthesize proteins. However, prokaryotes differ from eukaryotic cells in several ways.

Components of Prokaryotic Cells

A **prokaryotic cell** is a simple, single-celled (unicellular) organism that lacks a nucleus, or any other membrane-bound organelle. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in the central part of the cell: a darkened region called the nucleoid (Figure $Page3.3.1$).

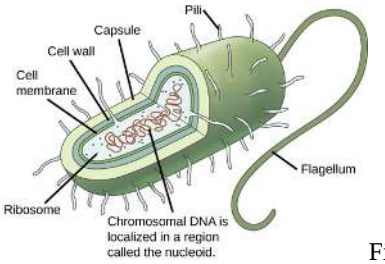


Figure $Page3.3.2$. This figure shows the generalized structure of a prokaryotic cell.

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Unlike Archaea and eukaryotes, bacteria have a cell wall made of peptidoglycan (molecules comprised of sugars and amino acids) and many have a polysaccharide capsule. The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili are used to exchange genetic material during a type of reproduction called conjugation. Fimbriae are protein appendages used by bacteria to attach to other cells.

Eukaryotic Cells

A **eukaryotic cell** is a cell that has a membrane-bound nucleus and other membrane-bound compartments called **organelles.** There are many different types of organelles, each with a highly specialized function (see Figure $Page3.3.3$). The word eukaryotic means "true kernel" or "true nucleus," alluding to the presence of the membrane-bound nucleus in these cells. The word "organelle" means "little organ," and, as already mentioned, organelles have specialized cellular functions, just as the organs of your body have specialized functions.

Cell Size

At 0.1–5.0 µm in diameter, most prokaryotic cells are significantly smaller than eukaryotic cells, which have diameters ranging from 10–100 µm (Figure $Page3.3.3$). The small size of prokaryotes allows ions and organic molecules that enter them to quickly spread to other parts of the cell. Similarly, any wastes produced within a prokaryotic cell can quickly move out. However, larger eukaryotic cells have evolved different structural adaptations to enhance cellular transport. Indeed, the large size of these cells would not be possible without these adaptations. In general, cell size is limited because volume increases much more quickly than does cell surface area. As a cell becomes larger, it becomes more and more difficult for the cell to acquire sufficient materials to support the processes inside the cell, because the relative size of the surface area through which materials must be transported declines.

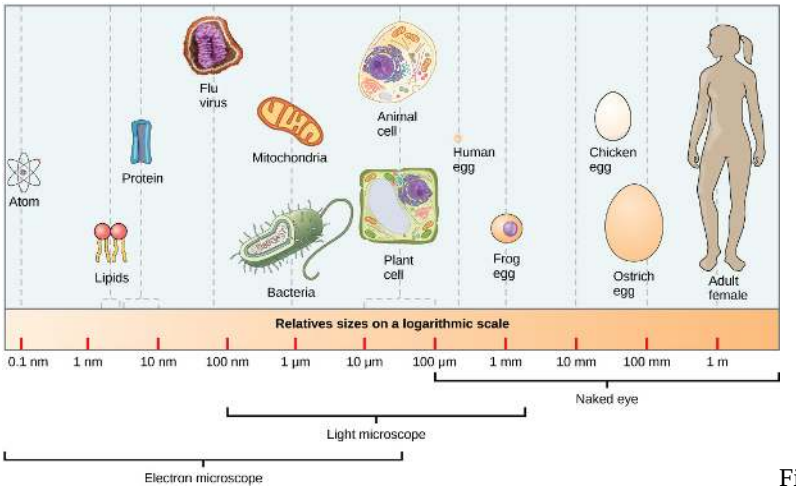


Figure $Page3.3.3$. This figure shows the relative sizes of different kinds of cells and cellular components. An adult human is shown for comparison.

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Animal Cells versus Plant Cells

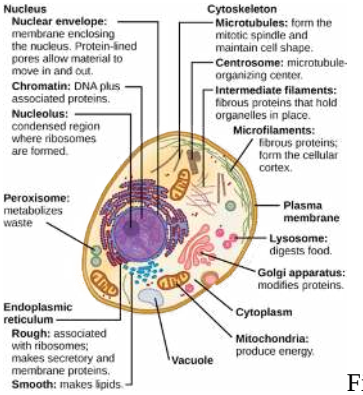


Figure $Page 3.3.4$. An example of a typical animal cell.

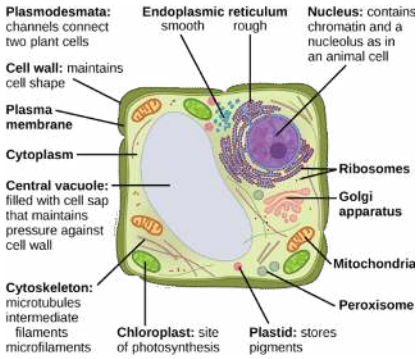


Figure $Page 3.3.5$. An example of a typical plant cell.

Despite their fundamental similarities, there are some striking differences between animal and plant cells (Figure $Page 3.3.3$). Animal cells have centrioles, centrosomes, and lysosomes, whereas plant cells do not. Plant cells have a rigid cell wall that is external to the plasma membrane, chloroplasts, plasmodesmata, and plastids used for storage, and a large central vacuole, whereas animal cells do not.

Chloroplasts

From an ecological perspective, **chloroplasts** are a particularly important type of organelle because they perform photosynthesis. Photosynthesis forms the foundation of food chains in most ecosystems. Chloroplasts are only found in eukaryotic cells such as plants and algae. During photosynthesis, carbon dioxide, water, and light energy are used to make glucose and molecular oxygen. One major difference between algae/plants and animals is that plants/algae are able to make their own food, like glucose, whereas animals must obtain food by consuming other organisms.

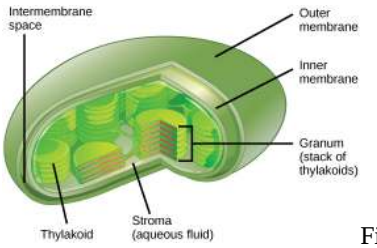


Figure $Page 3.3.6$. This simplified diagram of a chloroplast shows its structure.

Chloroplasts have outer and inner membranes, but within the space enclosed by a chloroplast's inner membrane is a set of interconnected and stacked, fluid-filled membrane sacs called thylakoids (Figure $Page 3.3.4$ below). Each stack of thylakoids is called a granum (plural = grana). The fluid enclosed by the inner membrane and surrounding the grana is called the stroma. Each structure within the chloroplast has an important function, which is enabled by its particular shape. A common theme in biology is that form and function are interrelated. For example, the membrane-rich stacks of the thylakoids provide ample surface area to embed the proteins and pigments that are vital to photosynthesis.

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Page 3.4: Energy Enters Ecosystems Through Photosynthesis

Cells run on the chemical energy found mainly in carbohydrate molecules, and the majority of these molecules are produced by one process: photosynthesis. Through photosynthesis, certain organisms convert solar energy (sunlight) into chemical energy, which is then used to build carbohydrate molecules. The energy stored in the bonds to hold these molecules together is released when an organism breaks down food. Cells then use this energy to perform work, such as movement. The energy that is harnessed from photosynthesis enters the ecosystems of our planet continuously and is transferred from one organism to another. Therefore, directly or indirectly, the process of photosynthesis provides most of the energy required by living things on Earth. Photosynthesis also results in the release of oxygen into the atmosphere. In short, to eat and breathe humans depend almost entirely on the organisms that carry out photosynthesis.

Solar Dependence and Food Production



(a) (b) (c)

Figure *Page*3.4.1. (a) Plants, (b) algae, and (c) certain bacteria, called cyanobacteria, are photoautotrophs that can carry out photosynthesis. Algae can grow over enormous areas in water, at times completely covering the surface. (credit a: Steve Hillebrand, U.S. Fish and Wildlife Service; credit b: “eutrophication&hypoxia”/Flickr; credit c: NASA; scale-bar data from Matt Russell)

Some organisms can carry out photosynthesis, whereas others cannot. An **autotroph** is an organism that can produce its own food. The Greek roots of the word autotroph mean “self” (auto) “feeder” (troph). Plants are the best-known autotrophs, but others exist, including certain types of bacteria and algae (Figure *Page*3.4.1). Oceanic algae contribute enormous quantities of food and oxygen to global food chains. More specifically, plants are **photoautotrophs**, a type of autotroph that uses sunlight and carbon from carbon dioxide to synthesize chemical energy in the form of carbohydrates. All organisms carrying out photosynthesis require sunlight.



Figure *Page*3.4.2. The energy stored in carbohydrate molecules from photosynthesis passes through the food chain. The predator that eats these deer is getting energy that originated in the photosynthetic vegetation that the deer consumed. (credit: Steve VanRiper, U.S. Fish and Wildlife Service)

Heterotrophs are organisms incapable of photosynthesis that must therefore obtain energy and carbon from food by consuming other organisms. The Greek roots of the word *heterotroph* mean “other” (*hetero*) “feeder” (*troph*), meaning that their food comes from other organisms. Even if the organism being consumed is another animal, it traces its stored energy back to autotrophs and the process of photosynthesis. Humans are heterotrophs, as are all animals and fungi. Heterotrophs depend on autotrophs, either directly or indirectly. For example, a deer obtains energy by eating plants. A wolf eating a deer obtains energy that originally came from the plants eaten by that deer (Figure *Page*3.4.2). Using this reasoning, all food eaten by humans can be traced back to autotrophs that carry out photosynthesis.

Summary of Photosynthesis

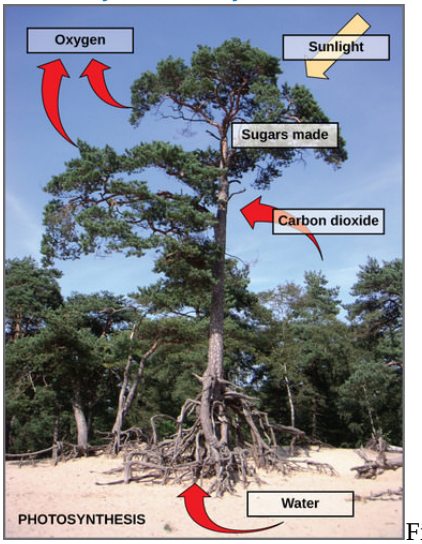


Figure $Page 3.4.3$. Photosynthesis uses solar energy, carbon dioxide, and water to release oxygen and to produce energy-storing sugar molecules.

Photosynthesis requires sunlight, carbon dioxide, and water as starting reactants (Figure $Page 3.4.3$). After the process is complete, photosynthesis releases oxygen and produces carbohydrate molecules, most commonly glucose. These sugar molecules contain the energy that living things need to survive. The complex reactions of photosynthesis can be summarized by the chemical equation shown in Figure $Page 3.4.4$ below.

Although the equation looks simple, the many steps that take place during photosynthesis are actually quite complex. In plants, photosynthesis takes place primarily in the chloroplasts of leaves. Chloroplasts have a double (inner and outer) membrane. Within the chloroplast is a third membrane that forms stacked, disc-shaped structures called thylakoids. Embedded in the thylakoid membrane are molecules of **chlorophyll**, a pigment (a molecule that absorbs light) through which the entire process of photosynthesis begins.

Photosynthesis Equation						
Carbon dioxide	+	Water	SUNLIGHT →	Sugar	+	Oxygen
$6CO_2$		$6H_2O$		$C_6H_{12}O_6$		$6O_2$

Figure $Page 3.4.4$. This equation means that six molecules of carbon dioxide (CO2) combine with six molecules of water (H2O) in the presence of sunlight. This produces one molecule of glucose ($C_6H_{12}O_6$) and six molecules of oxygen (O2).

The Two Parts of Photosynthesis

Photosynthesis takes place in two stages: the light-dependent reactions and the Calvin cycle**.** In the **light-dependent reactions** chlorophyll absorbs energy from sunlight and then converts it into chemical energy with the aid of water. The light-dependent reactions release **oxygen** as a byproduct from the splitting of water. In the **Calvin cycle**, the chemical energy derived from the light-dependent reactions drives both the capture of carbon in **carbon dioxide** molecules and the subsequent assembly of sugar molecules.

The Global Significance of Photosynthesis

The process of photosynthesis is crucially important to the biosphere for the following reasons:

1. It creates O_2, which is important for two reasons. The molecular oxygen in Earth's atmosphere was created by photosynthetic organisms; without photosynthesis there would be no O_2 to support cellular respiration (see chapter 3.2) needed by complex, multicellular life. Photosynthetic bacteria were likely the first organisms to perform photosynthesis, dating back 2-3 billion years ago. Thanks to their activity, and a diversity of present-day photosynthesizing organisms, Earth's atmosphere is currently about 21% O_2. Also, this O_2 is vital for the creation of the ozone layer (see chapter 10.2), which protects life from harmful ultraviolet radiation emitted by the sun. Ozone (O_3) is created from the breakdown and reassembly of O_2.

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2. It provides energy for nearly all ecosystems. By transforming light energy into chemical energy, photosynthesis provides the energy used by organisms, whether those organisms are plants, grasshoppers, wolves, or fungi. The only exceptions are found in very rare and isolated ecosystems, such as near deep sea hydrothermal vents where organisms get energy that originally came from minerals, not the sun.
3. It provides the carbon needed for organic molecules. Organisms are primarily made of two things: water and organic molecules, the latter being carbon based. Through the process of **carbon fixation,** photosynthesis takes carbon from CO_2 and converts it into sugars (which are organic). Carbon in these sugars can be re-purposed to create the other types of organic molecules that organisms need, such as lipids, proteins, and nucleic acids. For example, the carbon used to make your DNA was once CO_2 used by photosynthetic organisms (see section 3.1 for more information on food webs).

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Page 3.5: Energy Flow through Ecosystems



Figure $Page3.5.1$. A (a) tidal pool ecosystem in Matinicus Island, Maine, is a small ecosystem, while the (b) Amazon rainforest in Brazil is a large ecosystem. (credit a: modification of work by Jim Kuhn; credit b: modification of work by Ivan Mlinaric)

An **ecosystem** is a community of organisms and their abiotic (non-living) environment. Ecosystems can be small, such as the tide pools found near the rocky shores of many oceans, or large, such as those found in the tropical rainforest of the Amazon in Brazil (Figure $Page3.5.1$).

There are three broad categories of ecosystems based on their general environment: freshwater, marine, and terrestrial. Within these three categories are individual ecosystem types based on the environmental habitat and organisms present.

Freshwater ecosystems are the least common, occurring on only 1.8 percent of Earth's surface. These systems comprise lakes, rivers, streams, and springs; they are quite diverse and support a variety of animals, plants, fungi, protists and prokaryotes.

Marine ecosystems are the most common, comprising 75 percent of Earth's surface and consisting of three basic types: shallow ocean, deep ocean water, and deep ocean bottom. Shallow ocean ecosystems include extremely biodiverse coral reef ecosystems. Small photosynthetic organisms suspended in ocean waters, collectively known as **phytoplankton,** perform 40 percent of all photosynthesis on Earth. Deep ocean bottom ecosystems contain a wide variety of marine organisms. These ecosystems are so deep that light is unable to reach them.

Terrestrial ecosystems, also known for their diversity, are grouped into large categories called biomes. A **biome** is a large-scale community of organisms, primarily defined on land by the dominant plant types that exist in geographic regions of the planet with similar climatic conditions. Examples of biomes include tropical rainforests, savannas, deserts, grasslands, temperate forests, and tundras. Grouping these ecosystems into just a few biome categories obscures the great diversity of the individual ecosystems within them. For example, the saguaro cacti (*Carnegiea gigantean*) and other plant life in the Sonoran Desert, in the United States, are relatively diverse compared with the desolate rocky desert of Boa Vista, an island off the coast of Western Africa (Figure $Page3.5.2$).

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Figure $Page3.5.2$. Desert ecosystems, like all ecosystems, can vary greatly. The desert in (a) Saguaro National Park, Arizona, has abundant plant life, while the rocky desert of (b) Boa Vista island, Cape Verde, Africa, is devoid of plant life. (credit a: modification of work by Jay Galvin; credit b: modification of work by Ingo Wölbern)

A **food chain** is a linear sequence of organisms through which nutrients and energy pass as one organism eats another. The levels in the food chain are producers, primary consumers, higher-level consumers, and finally decomposers. These levels are used to describe ecosystem structure and dynamics. There is a single path through a food chain. Each organism in a food chain occupies a specific trophic level (energy level), its position in the food chain or food web.

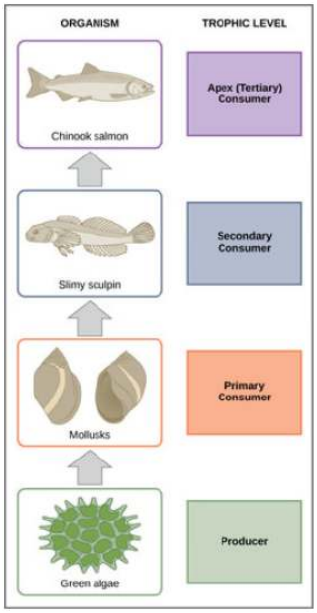


Figure $Page3.5.3$. These are the trophic levels of a food chain in Lake Ontario at the United States–Canada border. Energy and nutrients flow from photosynthetic green algae at the base to the top of the food chain: the Chinook salmon. (credit: modification of work by National Oceanic and Atmospheric Administration/NOAA)

In many ecosystems, the base, or foundation, of the food chain consists of photosynthetic organisms (plants or phytoplankton), which are called **producers**. The organisms that consume the producers are herbivores called **primary consumers**. **Secondary consumers** are usually carnivores that eat the primary consumers. **Tertiary consumers** are carnivores that eat other carnivores. Higher-level consumers feed on the next lower trophic levels, and so on, up to the organisms at the top of the food chain. In the Lake Ontario food chain, shown in Figure $Page3.5.3$, the Chinook salmon is the apex consumer at the top of this food chain.

One major factor that limits the number of steps in a food chain is energy. Energy is lost at each trophic level and between trophic levels as heat and in the transfer to decomposers (Figure $Page3.5.4$ below). Thus, after a limited number of trophic energy transfers, the amount of energy remaining in the food chain may not be great enough to support viable populations at higher trophic levels.

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There is a one problem when using food chains to describe most ecosystems. Even when all organisms are grouped into appropriate trophic levels, some of these organisms can feed at more than one trophic level. In addition, species feed on and are eaten by more than one species. In other words, the linear model of ecosystems, the food chain, is a hypothetical and overly simplistic representation of ecosystem structure. A holistic model—which includes all the interactions between different species and their complex interconnected relationships with each other and with the environment—is a more accurate and descriptive model for ecosystems. A **food web** is a concept that accounts for the multiple trophic (feeding) interactions between each species (Figure $Page 3.5.5$ below).

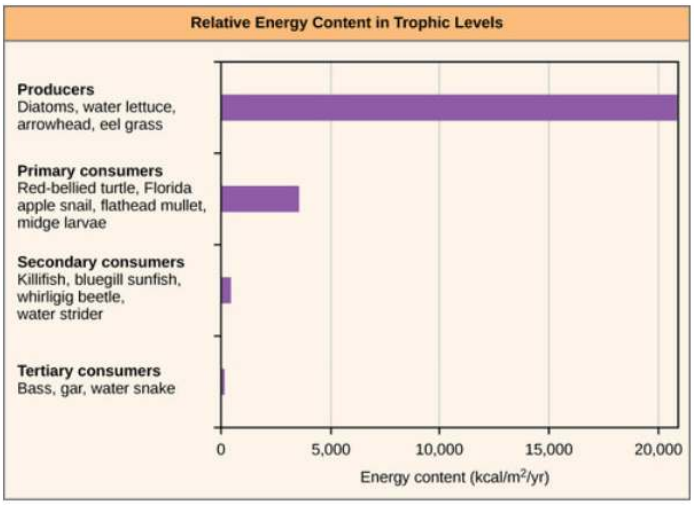


Figure $Page 3.5.4$. The relative energy in trophic levels in a Silver Springs, Florida, ecosystem is shown. Each trophic level has less energy available, and usually, but not always, supports a smaller mass of organisms at the next level.

Two general types of food webs are often shown interacting within a single ecosystem. A grazing food web has plants or other photosynthetic organisms at its base, followed by herbivores and various carnivores. A detrital food web consists of a base of organisms that feed on decaying organic matter (dead organisms), including **decomposers** (which break down dead and decaying organisms) and **detritivores**(which consume organic detritus). These organisms are usually bacteria, fungi, and invertebrate animals that recycle organic material back into the biotic part of the ecosystem as they themselves are consumed by other organisms.

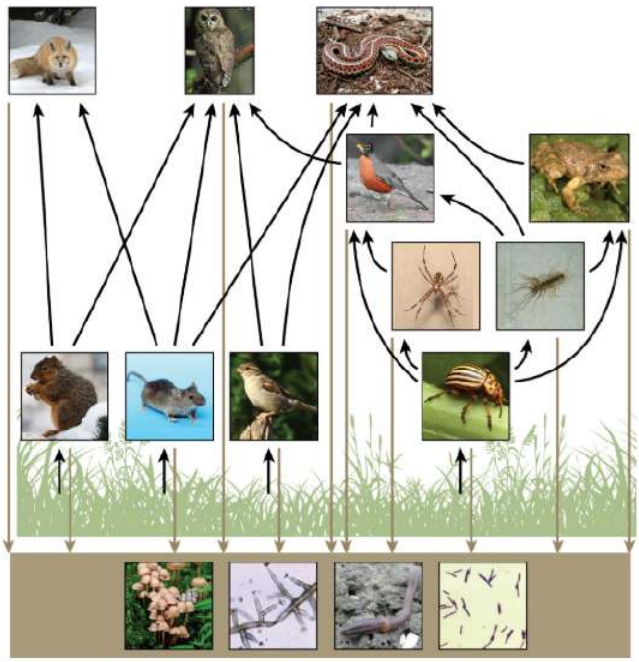


Figure $Page 3.5.5$. This food web shows the interactions between organisms across trophic levels. Arrows point from an organism that is consumed to the organism that consumes it. All the

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producers and consumers eventually become nourishment for the decomposers (fungi, mold, earthworms, and bacteria in the soil). (credit “fox”: modification of work by Kevin Bacher, NPS; credit “owl”: modification of work by John and Karen Hollingsworth, USFWS; credit “snake”: modification of work by Steve Jurvetson; credit “robin”: modification of work by Alan Vernon; credit “frog”: modification of work by Alessandro Catenazzi; credit “spider”: modification of work by “Sanba38″/Wikimedia Commons; credit “centipede”: modification of work by “Bauerph”/Wikimedia Commons; credit “squirrel”: modification of work by Dawn Huczek; credit “mouse”: modification of work by NIGMS, NIH; credit “sparrow”: modification of work by David Friel; credit “beetle”: modification of work by Scott Bauer, USDA Agricultural Research Service; credit “mushrooms”: modification of work by Chris Wee; credit “mold”: modification of work by Dr. Lucille Georg, CDC; credit “earthworm”: modification of work by Rob Hille; credit “bacteria”: modification of work by Don Stalons, CDC)

How Organisms Acquire Energy in a Food Web

All living things require energy in one form or another. At the cellular level, energy is used in most metabolic pathways (usually in the form of ATP), especially those responsible for building large molecules from smaller compounds. Living organisms would not be able to assemble complex organic molecules (proteins, lipids, nucleic acids, and carbohydrates) without a constant energy input.

Food-web diagrams illustrate how energy flows directionally through ecosystems. They can also indicate how efficiently organisms acquire energy, use it, and how much remains for use by other organisms of the food web. Energy is acquired by living things in two ways: autotrophs harness light or chemical energy and heterotrophs acquire energy through the consumption and digestion of other living or previously living organisms.

Photosynthetic and chemosynthetic organisms are autotrophs, which are organisms capable of synthesizing their own food (more specifically, capable of using inorganic carbon as a carbon source). Photosynthetic autotrophs (**photoautotrophs**) use sunlight as an energy source, and chemosynthetic autotrophs (**chemoautotrophs**) use inorganic molecules as an energy source. Autotrophs are critical for ecosystems because they occupy the trophic level containing producers. Without these organisms, energy would not be available to other living organisms, and life would not be possible.

Photoautotrophs, such as plants, algae, and photosynthetic bacteria, are the energy source for a majority of the world’s ecosystems. Photoautotrophs harness the Sun’s solar energy by converting it to chemical energy. The rate at which photosynthetic producers incorporate energy from the Sun is called **gross primary productivity**. However, not all of the energy incorporated by producers is available to the other organisms in the food web because producers must also grow and reproduce, which consumes energy. **Net primary productivity** is the energy that remains in the producers after accounting for these organisms’ metabolism and heat loss. The net productivity is then available to the primary consumers at the next trophic level.

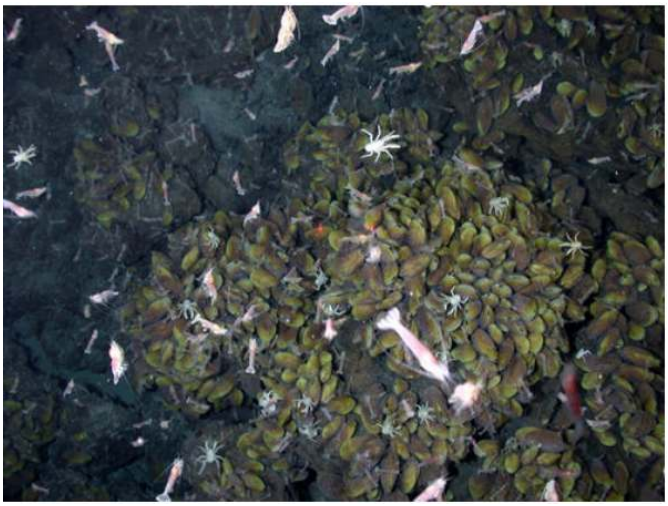


Figure $Page3.5.6$. Swimming shrimp, a few squat lobsters, and hundreds of vent mussels are seen at a hydrothermal vent at the bottom of the ocean. As no sunlight penetrates to this depth, the ecosystem is supported by chemoautotrophic bacteria and organic material that sinks from the ocean’s surface. This picture was taken in 2006 at the submerged NW Eifuku volcano off the coast of Japan by the National Oceanic and Atmospheric Administration (NOAA). The summit of this highly active volcano lies 1535 m below the surface.

Chemoautotrophs are primarily bacteria and archaea that are found in rare ecosystems where sunlight is not available, such as those associated with dark caves or hydrothermal vents at the bottom of the ocean (Figure $Page3.5.6$). Many chemoautotrophs in hydrothermal vents use hydrogen sulfide (H_2S), which is released from the vents, as a source of chemical energy. This allows them to synthesize complex organic molecules, such as glucose, for their own energy and, in turn, supplies energy to the rest of the ecosystem.

One of the most important consequences of ecosystem dynamics in terms of human impact is biomagnification. **Biomagnification** is the increasing concentration of persistent, toxic substances in organisms at each successive trophic level. These are substances that are lipid soluble and are stored in the fat reserves of each organism. Many substances have been shown to biomagnify, including classical studies with the pesticide dichlorodiphenyltrichloroethane (DDT), which were described in the 1960s bestseller *Silent Spring* by Rachel Carson. DDT was a commonly used pesticide before its dangers to apex consumers, such as the bald eagle, became known. DDT and other toxins are taken in by producers and passed on to successive levels of consumers at increasingly higher rates. As bald eagles feed on contaminated fish, their DDT levels rise. It was discovered that DDT caused the eggshells of birds to become fragile, which contributed to the bald eagle being listed as an endangered species under U.S. law. The use of DDT was banned in the United States in the 1970s.

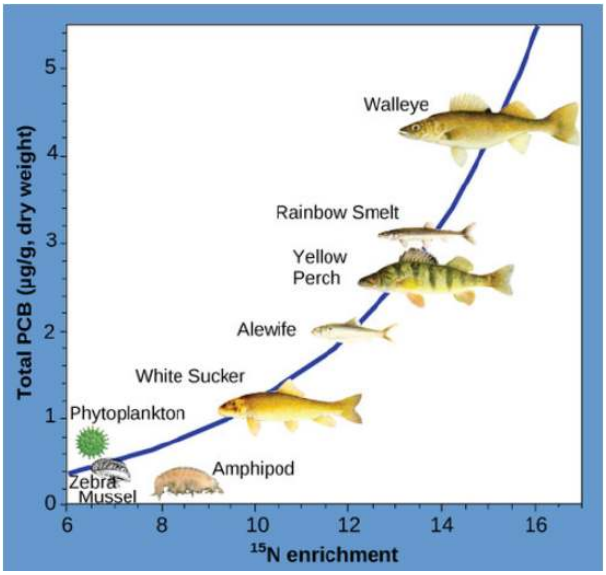


Figure $Page3.5.7$. This chart shows the PCB concentrations found at the various trophic levels in the Saginaw Bay ecosystem of Lake Huron. Notice that the fish in the higher trophic levels accumulate more PCBs than those in lower trophic levels. (credit: Patricia Van Hoof, NOAA)

Another substances that biomagnifies is polychlorinated biphenyl (PCB), which was used as coolant liquids in the United States until its use was banned in 1979. PCB was best studied in aquatic ecosystems where predatory fish species accumulated very high concentrations of the toxin that is otherwise exists at low concentrations in the environment. As illustrated in a study performed by the NOAA in the Saginaw Bay of Lake Huron of the North American Great Lakes (Figure $Page3.5.7$ below), PCB concentrations increased from the producers of the ecosystem (phytoplankton) through the different trophic levels of fish species. The apex consumer, the walleye, has more than four times the amount of PCBs compared to phytoplankton. Also, research found that birds that eat these fish may have PCB levels that are at least ten times higher than those found in the lake fish.

Other concerns have been raised by the biomagnification of heavy metals, such as mercury and cadmium, in certain types of seafood. The United States Environmental Protection Agency recommends that pregnant women and young children should not consume any swordfish, shark, king mackerel, or tilefish because of their high mercury content. These individuals are advised to eat fish low in mercury: salmon, shrimp, pollock, and catfish. Biomagnification is a good example of how ecosystem dynamics can affect our everyday lives, even influencing the food we eat.

Suggested Supplementary Reading

Canales, M. et al. 2018. 6 Things that Make Like on Earth Possible [Infographic]. *National Geographic*. March.

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Page 3.6: Biogeochemical Cycles

Energy flows directionally through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during energy transformation between trophic levels. Rather than flowing through an ecosystem, the matter that makes up organisms is conserved and recycled. The six most common elements associated with organic molecules—carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur—take a variety of chemical forms and may exist for long periods in the atmosphere, on land, in water, or beneath Earth's surface. Geologic processes, such as weathering, erosion, water drainage, and the subduction of the continental plates, all play a role in the cycling of elements on Earth. Because geology and chemistry have major roles in the study of these processes, the recycling of inorganic matter between living organisms and their nonliving environment are called **biogeochemical cycles**.

The six aforementioned elements are used by organisms in a variety of ways. Hydrogen and oxygen are found in water and organic molecules, both of which are essential to life. Carbon is found in all organic molecules, whereas nitrogen is an important component of nucleic acids and proteins. Phosphorus is used to make nucleic acids and the phospholipids that comprise biological membranes. Lastly, sulfur is critical to the three-dimensional shape of proteins.

The cycling of these elements is interconnected. For example, the movement of water is critical for the leaching of sulfur and phosphorus into rivers, lakes, and oceans. Minerals cycle through the biosphere between the biotic and abiotic components and from one organism to another.

The Water Cycle

The **hydrosphere** is the area of Earth where water movement and storage occurs: as liquid water on the surface (rivers, lakes, oceans) and beneath the surface (groundwater) or ice, (polar ice caps and glaciers), and as water vapor in the atmosphere.The human body is about 60 percent water and human cells are more than 70 percent water. Of the stores of water on Earth, 97.5 percent is salt water (see Figure $Page 3.6.1$ below). Of the remaining water, more than 99 percent is groundwater or ice. Thus, less than one percent of freshwater is present in lakes and rivers. Many organisms are dependent on this small percentage, a lack of which can have negative effects on ecosystems. Humans, of course, have developed technologies to increase water availability, such as digging wells to harvest groundwater, storing rainwater, and using desalination to obtain drinkable water from the ocean. Although this pursuit of drinkable water has been ongoing throughout human history, the supply of fresh water continues to be a major issue in modern times.

The various processes that occur during the cycling of water are illustrated in Figure $Page 3.6.2$ below. The processes include the following:

- evaporation and sublimation
- condensation and precipitation
- subsurface water flow
- surface runoff and snowmelt
- streamflow

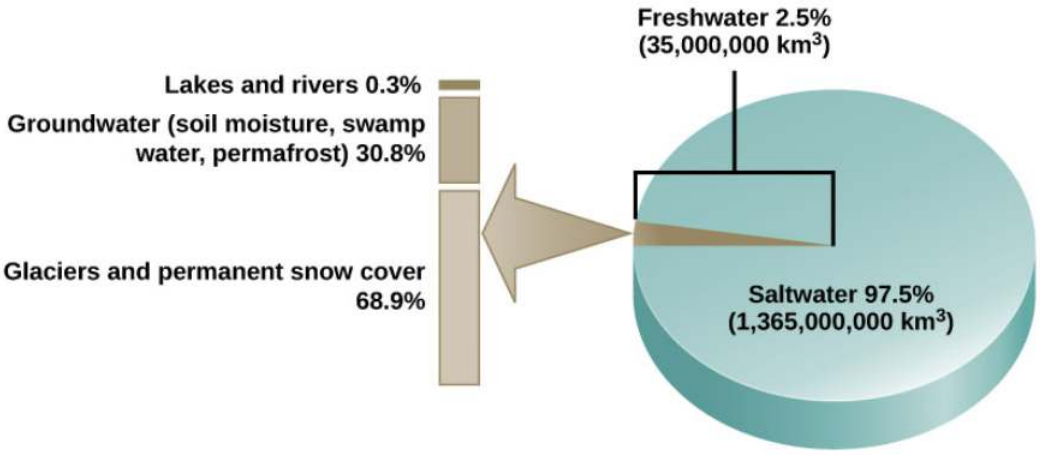


Figure $Page 3.6.1$. Only 2.5 percent of water on Earth is fresh water, and less than 1 percent of fresh water is easily accessible to living things.

The **water cycle** is driven by the Sun's energy as it warms the oceans and other surface waters. This leads to **evaporation** (liquid water to water vapor) of liquid surface water and **sublimation** (ice to water vapor) of frozen water, thus moving large amounts of water into the atmosphere as water vapor. Over time, this water vapor condenses into clouds as liquid or frozen droplets and eventually leads to **precipitation** (rain, snow, hail), which returns water to Earth's surface. Rain reaching Earth's surface may evaporate again, flow over the surface, or percolate into the ground. Most easily observed is **surface runoff**: the flow of freshwater over land either from rain or melting ice. Runoff can make its way through streams and lakes to the oceans.

In most natural terrestrial environments rain encounters vegetation before it reaches the soil surface. A significant percentage of water evaporates immediately from the surfaces of plants. What is left reaches the soil and begins to move down. Surface runoff will occur only if the soil becomes saturated with water in a heavy rainfall. Water in the soil can be taken up by plant roots. The plant will use some of this water for its own metabolism and some of that will find its way into animals that eat the plants, but much of it will be lost back to the atmosphere through a process known as **transpiration:** water enters the vascular system of plants through the roots and evaporates, or transpires, through the stomata (small microscope openings) of the leaves. Ecologists combine transpiration and evaporation into a single term that describes water returned to the atmosphere: **evapotranspiration**. Water in the soil that is not taken up by a plant and that does not evaporate is able to percolate into the subsoil and bedrock where it forms groundwater.

Groundwater is a significant, subsurface reservoir of fresh water. It exists in the pores between particles in dirt, sand, and gravel or in the fissures in rocks. Groundwater can flow slowly through these pores and fissures and eventually finds its way to a stream or lake where it becomes part of the surface water again. Many streams flow not because they are replenished from rainwater directly but because they receive a constant inflow from the groundwater below. Some groundwater is found very deep in the bedrock and can persist there for millennia. Most groundwater reservoirs, or **aquifers**, are the source of drinking or irrigation water drawn up through wells. In many cases these aquifers are being depleted faster than they are being replenished by water percolating down from above.

Rain and surface runoff are major ways in which minerals, including phosphorus and sulfur, are cycled from land to water. The environmental effects of runoff will be discussed later as these cycles are described.

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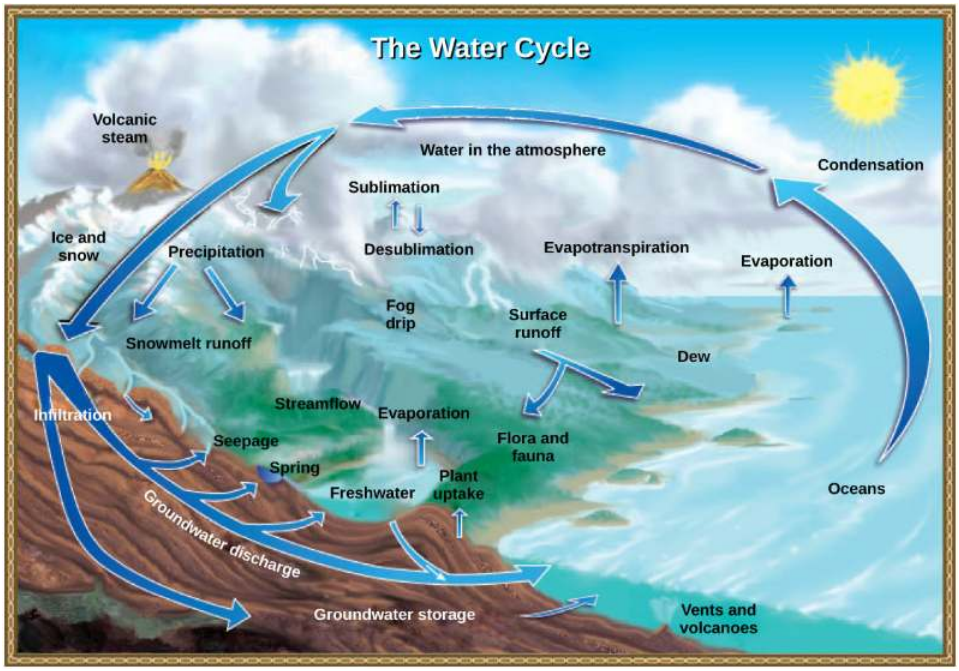


Figure $Page 3.6.2$. Water from the land and oceans enters the atmosphere by evaporation or sublimation, where it condenses into clouds and falls as rain or snow. Precipitated water may enter freshwater bodies or infiltrate the soil. The cycle is complete when surface or groundwater reenters the ocean. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

The Carbon Cycle

Carbon is the second most abundant element in organisms, by mass. Carbon is present in all organic molecules (and some molecules that are not organic such as CO_2), and its role in the structure of biomolecules is of primary importance. Carbon compounds contain energy, and many of these compounds from dead plants and algae have fossilized over millions of years and are known as **fossil fuels**. Since the 1800s, the use of fossil fuels has accelerated. Since the beginning of the Industrial Revolution the demand for Earth's limited fossil fuel supplies has risen, causing the amount of carbon dioxide in our atmosphere to drastically increase. This increase in carbon dioxide is associated with climate change and is a major environmental concern worldwide.

The **carbon cycle** is most easily studied as two interconnected subcycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes. The entire carbon cycle is shown in Figure $Page 3.6.3$ below.

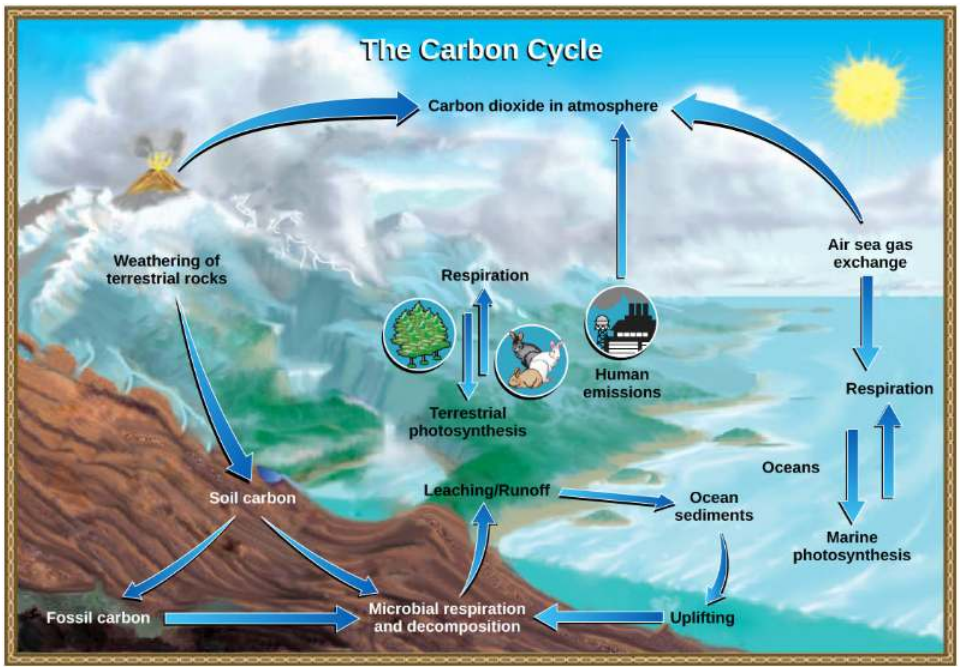


Figure $Page 3.6.3$. Carbon dioxide gas exists in the atmosphere and is dissolved in water. Photosynthesis converts carbon dioxide gas to organic carbon, and respiration cycles the organic carbon back into carbon dioxide gas. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground and becomes fossilized. Volcanic activity and, more recently, human emissions bring this stored carbon back into the carbon cycle. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

The Biological Carbon Cycle

Organisms are connected in many ways, even among different ecosystems. A good example of this connection is the exchange of carbon between heterotrophs and autotrophs by way of atmospheric carbon dioxide. Carbon dioxide (CO_2) is the basic building block that autotrophs use to build high-energy compounds such as glucose. The energy harnessed from the Sun is used by these organisms to form the covalent bonds that link carbon atoms together. These chemical bonds store this energy for later use in the process of respiration. Most terrestrial autotrophs obtain their carbon dioxide directly from the atmosphere, while marine autotrophs acquire it in the dissolved form (bicarbonate, HCO_3^-).

Carbon is passed from producers to higher trophic levels through consumption. For example, when a cow (primary consumer) eats grass (producer), it obtains some of the organic molecules originally made by the plant's photosynthesis. Those organic compounds can then be passed to higher trophic levels, such as humans, when we eat the cow. At each level, however, organisms are performing **respiration**, a process in which organic molecules are broken down to release energy. As these organic molecules are broken down, carbon is removed from food molecules to form CO_2, a gas that enters the atmosphere. Thus, CO_2 is a byproduct of respiration. Recall that CO_2 is consumed by producers during photosynthesis to make organic molecules. As these molecules are broken down during respiration, the carbon once again enters the atmosphere as CO_2. Carbon exchange like this potentially connects all organisms on Earth. Think about this: the carbon in your DNA was once part of plant; millions of years ago perhaps it was part of dinosaur.

The Biogeochemical Carbon Cycle

The movement of carbon through land, water, and air is complex, and, in many cases, it occurs much more slowly than the movement between organisms. Carbon is stored for long periods in what are known as carbon reservoirs, which include the atmosphere, bodies of liquid water (mostly oceans), ocean sediment, soil, rocks (including fossil fuels), and Earth's interior.

As stated, the atmosphere is a major reservoir of carbon in the form of carbon dioxide that is essential to the process of photosynthesis. The level of carbon dioxide in the atmosphere is greatly influenced by the reservoir of carbon in the oceans. The exchange of carbon between the atmosphere and water reservoirs influences how much carbon is found in each. Carbon dioxide (CO_2) from the atmosphere dissolves in water and reacts with water molecules to form ionic compounds. Some of these ions combine with calcium ions in the seawater to form calcium carbonate ($CaCO_3$), a major component of the shells of marine

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organisms. These organisms eventually die and their shells form sediments on the ocean floor. Over geologic time, the calcium carbonate forms limestone, which comprises the largest carbon reservoir on Earth.

On land, carbon is stored in soil as organic carbon as a result of the decomposition of organisms or from weathering of terrestrial rock and minerals (the world's soils hold significantly more carbon than the atmosphere, for comparison). Deeper underground are fossil fuels, the anaerobically decomposed remains of plants and algae that lived millions of years ago. Fossil fuels are considered a non-renewable resource because their use far exceeds their rate of formation. A **non-renewable resource** is either regenerated very slowly or not at all. Another way for carbon to enter the atmosphere is from land (including land beneath the surface of the ocean) by the eruption of volcanoes and other geothermal systems. Carbon sediments from the ocean floor are taken deep within Earth by the process of **subduction**: the movement of one tectonic plate beneath another. Carbon is released as carbon dioxide when a volcano erupts or from volcanic hydrothermal vents.

The Nitrogen Cycle

Getting nitrogen into living organisms is difficult. Plants and phytoplankton are not equipped to incorporate nitrogen from the atmosphere (where it exists as tightly bonded, triple covalent N_2) even though this molecule comprises approximately 78 percent of the atmosphere. Nitrogen enters the living world through free-living and symbiotic bacteria, which incorporate nitrogen into their organic molecules through specialized biochemical processes. Certain species of bacteria are able to perform **nitrogen fixation**, the process of converting nitrogen gas into ammonia (NH_3), which spontaneously becomes ammonium (NH_4^+). Ammonium is converted by bacteria into nitrites (NO_2^-) and then nitrates (NO_3^-). At this point, the nitrogen-containing molecules are used by plants and other producers to make organic molecules such as DNA and proteins. This nitrogen is now available to consumers.

Organic nitrogen is especially important to the study of ecosystem dynamics because many ecosystem processes, such as primary production, are limited by the available supply of nitrogen. As shown in Figure $Page 3.6.4$ below, the nitrogen that enters living systems is eventually converted from organic nitrogen back into nitrogen gas by bacteria (Figure $Page 3.6.4$). The process of **denitrification** is when bacteria convert the nitrates into nitrogen gas, thus allowing it to re-enter the atmosphere.

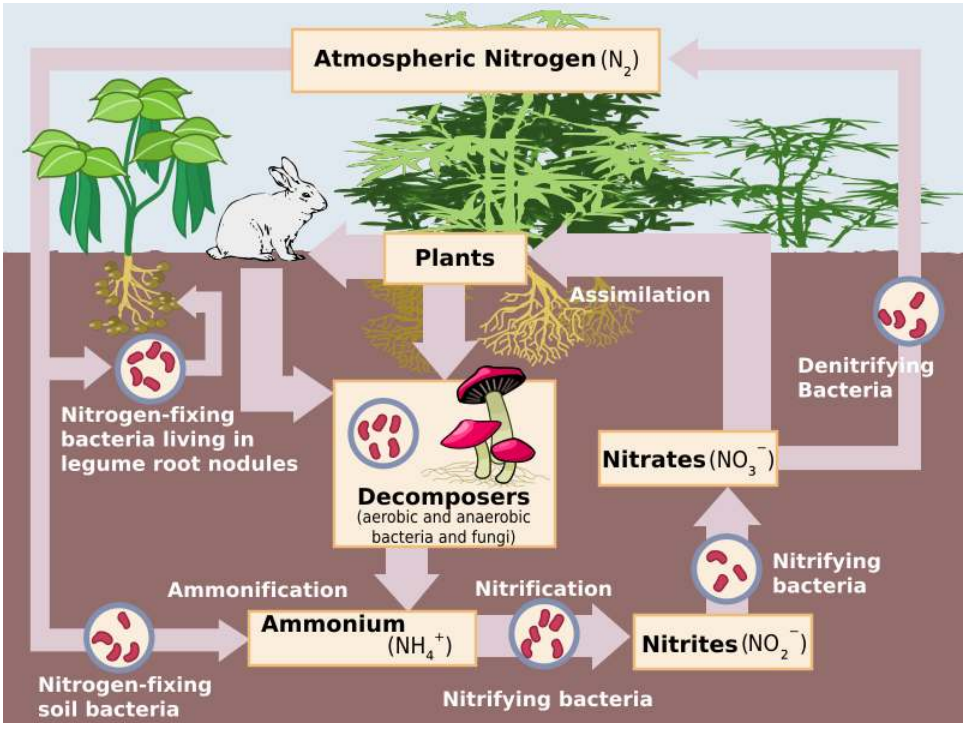


Figure $Page 3.6.4$. Nitrogen enters the living world from the atmosphere via nitrogen-fixing bacteria. This nitrogen and nitrogenous waste from animals is then processed back into gaseous nitrogen by soil bacteria, which also supply terrestrial food webs with the organic nitrogen they need. (credit: *"Nitrogen cycle" by Johann Dréo & Raeky is licensed under CC BY-SA 3.0)*

Human activity can alter the nitrogen cycle by two primary means: the combustion of fossil fuels, which releases different nitrogen oxides, and by the use of artificial fertilizers (which contain nitrogen and phosphorus compounds) in agriculture, which are then

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washed into lakes, streams, and rivers by surface runoff. Atmospheric nitrogen (other than N_2) is associated with several effects on Earth's ecosystems including the production of acid rain (as nitric acid, HNO_3) and greenhouse gas effects (as nitrous oxide, N_2O), potentially causing climate change. A major effect from fertilizer runoff is saltwater and freshwater **eutrophication**, a process whereby nutrient runoff causes the overgrowth of algae, the depletion of oxygen, and death of aquatic fauna.

In marine ecosystems, nitrogen compounds created by bacteria, or through decomposition, collects in ocean floor sediments. It can then be moved to land in geologic time by uplift of Earth's crust and thereby incorporated into terrestrial rock. Although the movement of nitrogen from rock directly into living systems has been traditionally seen as insignificant compared with nitrogen fixed from the atmosphere, a recent study showed that this process may indeed be significant and should be included in any study of the global nitrogen cycle.

The Phosphorus Cycle

Phosphorus is an essential nutrient for living processes. It is a major component of nucleic acids and phospholipids, and, as calcium phosphate, it makes up the supportive components of our bones. Phosphorus is often the limiting nutrient (necessary for growth) in aquatic, particularly freshwater, ecosystems.

Phosphorus occurs in nature as the phosphate ion (PO_4^{3-}). In addition to phosphate runoff as a result of human activity, natural surface runoff occurs when it is leached from phosphate-containing rock by weathering, thus sending phosphates into rivers, lakes, and the ocean. This rock has its origins in the ocean. Phosphate-containing ocean sediments form primarily from the bodies of ocean organisms and from their excretions. However, volcanic ash, aerosols, and mineral dust may also be significant phosphate sources. This sediment then is moved to land over geologic time by the uplifting of Earth's surface. (Figure below)

Phosphorus is also reciprocally exchanged between phosphate dissolved in the ocean and marine organisms. The movement of phosphate from the ocean to the land and through the soil is extremely slow, with the average phosphate ion having an oceanic residence time between 20,000 and 100,000 years.

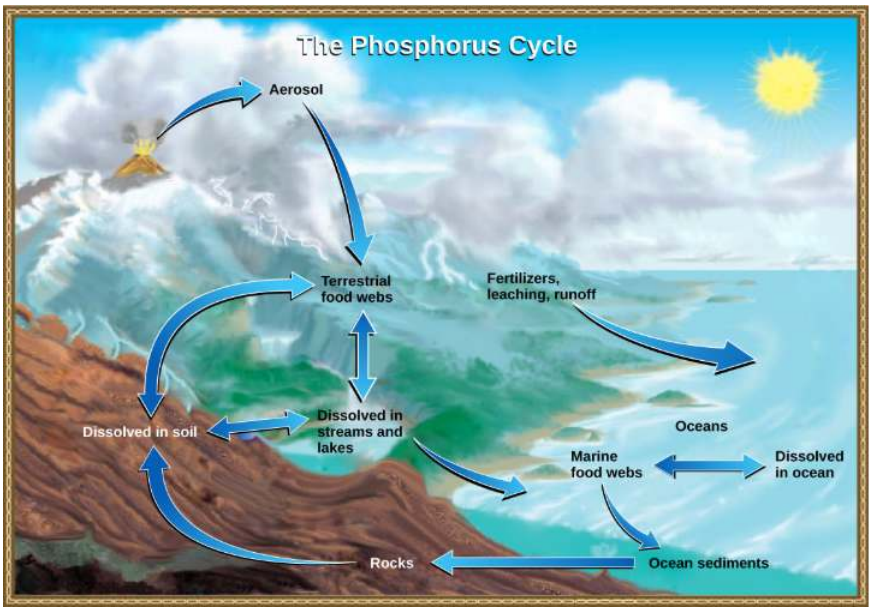


Figure $Page 3.6.5$. In nature, phosphorus exists as the phosphate ion (PO43-). Weathering of rocks and volcanic activity releases phosphate into the soil, water, and air, where it becomes available to terrestrial food webs. Phosphate enters the oceans in surface runoff, groundwater flow, and river flow. Phosphate dissolved in ocean water cycles into marine food webs. Some phosphate from the marine food webs falls to the ocean floor, where it forms sediment. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

Excess phosphorus and nitrogen that enter these ecosystems from fertilizer runoff and from sewage cause excessive growth of algae. The subsequent death and decay of these organisms depletes dissolved oxygen, which leads to the death of aquatic organisms such as shellfish and fish. This process is responsible for dead zones in lakes and at the mouths of many major rivers and for massive fish kills, which often occur during the summer months (see Figure $Page 3.6.6$ below).

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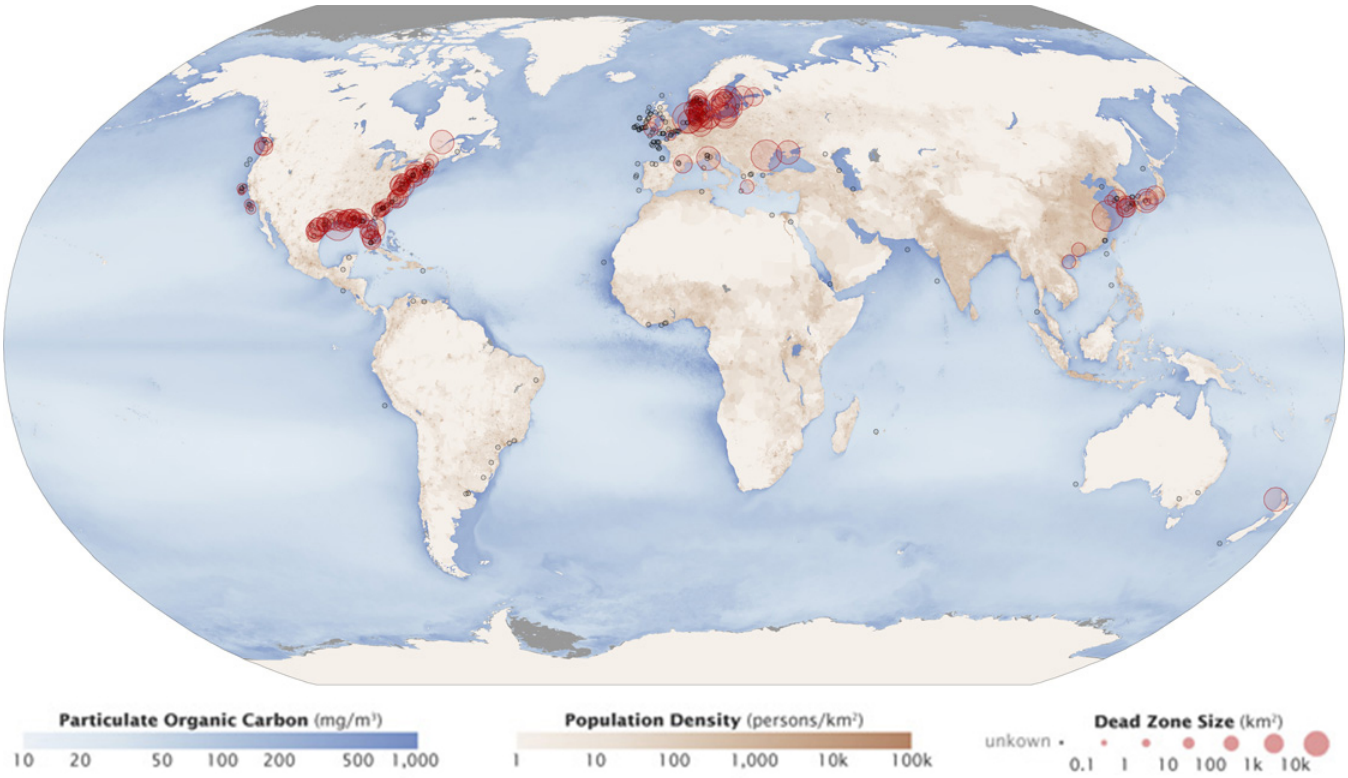


Figure $Page 3.6.6$. Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. Worldwide, large dead zones are found in coastal areas of high population density. (credit: NASA Earth Observatory)

A **dead zone** is an area in lakes and oceans near the mouths of rivers where large areas are periodically depleted of their normal flora and fauna. These zones are caused by eutrophication coupled with other factors including oil spills, dumping toxic chemicals, and other human activities. The number of dead zones has increased for several years, and more than 400 of these zones were present as of 2008. One of the worst dead zones is off the coast of the United States in the Gulf of Mexico: fertilizer runoff from the Mississippi River basin created a dead zone of over 8,463 square miles. Phosphate and nitrate runoff from fertilizers also negatively affect several lake and bay ecosystems including the Chesapeake Bay in the eastern United States.

The Sulfur Cycle

Sulfur is an essential element for the molecules of living things. As part of the amino acid cysteine, it is involved in the formation of proteins. As shown in Figure $Page 3.6.7$ below, sulfur cycles between the oceans, land, and atmosphere. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), which enters the atmosphere in three ways: first, from the decomposition of organic molecules; second, from volcanic activity and geothermal vents; and, third, from the burning of fossil fuels by humans.

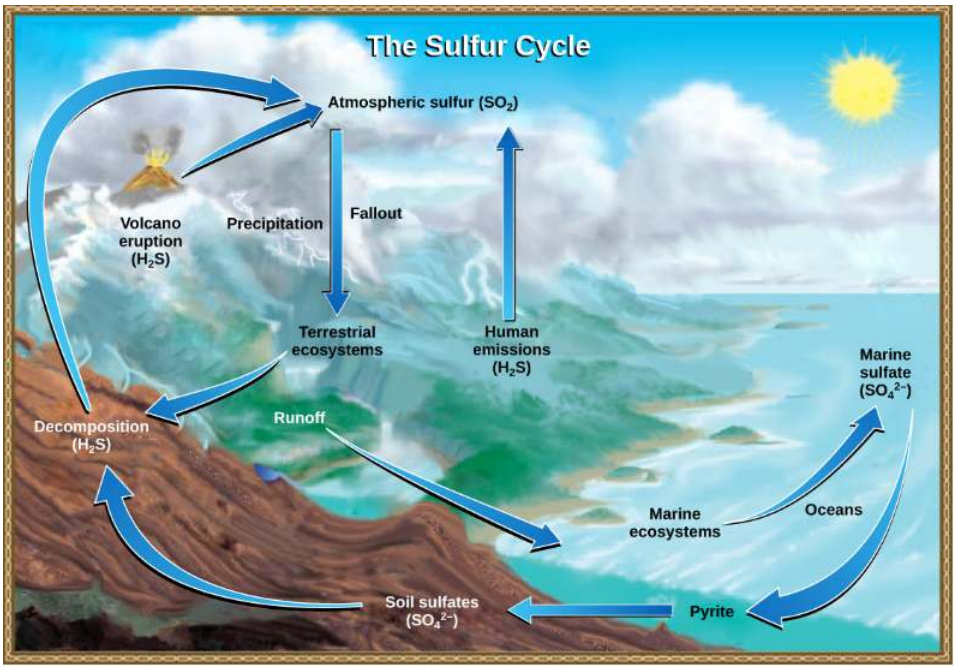


Figure *Page*3.6.7. Sulfur dioxide from the atmosphere becomes available to terrestrial and marine ecosystems when it is dissolved in precipitation as weak sulfuric acid or when it falls directly to Earth as fallout. Weathering of rocks also makes sulfates available to terrestrial ecosystems. Decomposition of living organisms returns sulfates to the ocean, soil, and atmosphere. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

On land, sulfur is deposited in four major ways: precipitation, direct fallout from the atmosphere, rock weathering, and geothermal vents. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), and as rain falls through the atmosphere, sulfur is dissolved in the form of weak sulfuric acid (H_2SO_4). Sulfur can also fall directly from the atmosphere in a process called fallout. Also, as sulfur-containing rocks weather, sulfur is released into the soil. These rocks originate from ocean sediments that are moved to land by the geologic uplifting of ocean sediments. Terrestrial ecosystems can then make use of these soil sulfates (SO_4^{2-}), which enter the food web by being taken up by plant roots. When these plants decompose and die, sulfur is released back into the atmosphere as hydrogen sulfide (H_2S) gas.

Sulfur enters the ocean in runoff from land, from atmospheric fallout, and from underwater geothermal vents. Some ecosystems rely on chemoautotrophs using sulfur as a biological energy source. This sulfur then supports marine ecosystems in the form of sulfates.

Human activities have played a major role in altering the balance of the global sulfur cycle. The burning of large quantities of fossil fuels, especially from coal, releases larger amounts of hydrogen sulfide gas into the atmosphere. As rain falls through this gas, it creates the phenomenon known as acid rain, which damages the natural environment by lowering the pH of lakes, thus killing many of the resident plants and animals. **Acid rain** is corrosive rain caused by rainwater falling to the ground through sulfur dioxide gas, turning it into weak sulfuric acid, which causes damage to aquatic ecosystems. Acid rain also affects the man-made environment through the chemical degradation of buildings. For example, many marble monuments, such as the Lincoln Memorial in Washington, DC, have suffered significant damage from acid rain over the years. These examples show the wide-ranging effects of human activities on our environment and the challenges that remain for our future.

Suggested Supplementary Reading

Bruckner, M. 2018. The Gulf of Mexico Dead Zone. [Website] <https://serc.carleton.edu/microbelif...one/index.html>

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Page 3.S: Matter, Energy, and Life (Summary)

Summary

Matter is anything that occupies space and has mass. It is made up of atoms of different elements. Elements that occur naturally have unique qualities that allow them to combine in various ways to create compounds or molecules. Atoms, which consist of protons, neutrons, and electrons, are the smallest units of an element that retain all of the properties of that element. Electrons can be donated or shared between atoms to create bonds, including ionic, covalent, and hydrogen bonds. The pH of a solution is a measure of the concentration of hydrogen ions in the solution. Living things are carbon-based because carbon plays such a prominent role in the chemistry of living things.

A cell is the smallest unit of life. Most cells are so small that they cannot be viewed with the naked eye. The unified cell theory states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells. Each cell runs on the chemical energy found mainly in carbohydrate molecules (food), and the majority of these molecules are produced by one process: photosynthesis. Through photosynthesis, certain organisms convert solar energy (sunlight) into chemical energy, which is then used to build carbohydrate molecules. Directly or indirectly, the process of photosynthesis provides most of the energy required by living things on earth. Photosynthesis also results in the release of oxygen into the atmosphere. In short, to eat and breathe, humans depend almost entirely on the organisms that carry out photosynthesis.

Review Questions

1. You analyze a sample of carbon and determine that 6% of the carbon atoms in your sample have a mass number (atomic mass) greater than 12, (12 is the normal atomic mass of carbon). Based on these results, which of the following can you reasonably conclude?
   A. 6% of the carbon sample is a different element
   B. 6% of the sample is comprised of carbon isotopes
   C. 6% of the sample is comprised of carbon ions
   D. 94% of the sample is comprised of carbon radioisotopes
   E. 94% of the sample contains covalent bonds
2. An atom that has an electrical charge due to having a number of electrons unequal to the number of protons is considered a(n)…
   A. Isotope
   B. Ion
   C. Element
   D. Molecule
   E. Acid
3. The atomic number for the element fluorine is 9 and its mass number is 19. How many neutrons does a normal atom of fluorine have?
   A. 0
   B. 9
   C. 10
   D. 19
   E. Impossible to determine with the information given
4. Which one of the following is not one of the four major classes of organic compounds?
   A. Nucleic acids
   B. Water
   C. Proteins
   D. Carbohydrates
   E. Lipids
5. You are working as an astrobiologist for NASA and are asked to analyze the first ever samples returned to Earth from Mars. How would you recognize if organic molecules were present in the samples?
   A. Test for isotopes of carbon

B. Look for the presence of hydrogen bonds
C. Search for chemicals with carbon to hydrogen bonds
D. Analyze the percentage of molecules with covalent bonds
E. Measure the pH of the samples

6. A micro-organism is viewed through a microscope and is determined to be made of a single cell that lacks organelles. From this information, which of the following can you conclude?
   A. The organism belongs to Domain Bacteria
   B. The organism belongs to Domain Eukarya
   C. The organism belongs to Domain Archaea
   D. The cell is prokaryotic
   E. The cell is eukaryotic
7. Which one of the following terms describes the complete set of chemical reactions that occur within cells?
   A. Metabolism
   B. Cellular respiration
   C. Calvin Cycle
   D. Bioenergetics
   E. Thermodynamics
8. Which one of the following is most strongly associated with kinetic energy?
   A. Atomic force
   B. Static position in a gravitational field
   C. Chemical energy
   D. Movement
   E. Covalent bonds
9. Which one of the following would help remove more CO_2 from the atmosphere?
   A. Planting more trees
   B. Burning less fossil fuels
   C. Increase the number of heterotrophs
   D. Decrease the number of autotrophs
   E. All of the above.
10. Water is essential to life because it has many special properties. Which one of the following is a special property of water?
    A. It is able to covalently bond to other water molecules
    B. It is good at dissolving other substances
    C. It easily heats up.
    D. It easily cools.
    E. It has a low surface tension

See Appendix for answers

11. What is matter?
12. What are elements?
13. Describe the interrelationship between protons, neutrons, and electrons, and the ways in which electrons can be donated or shared between atoms.
14. What is energy? Describe the two major types of energy.
15. Why is it often said that life is “carbon-based”?
16. Describe the roles of cells in organisms.
17. What is the cell theory?
18. Name examples of prokaryotic and eukaryotic organisms.
19. How are photosynthesis and cellular respiration complementary processes?
20. Why are carnivores, such as lions, dependent on photosynthesis to survive?

Additional Materials:

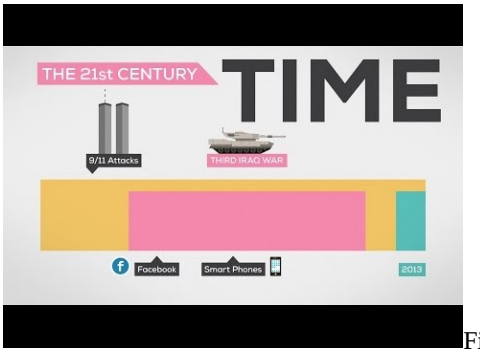


Figure $Page3.S.1$. A video that provides some perspective about time, history, life, the universe, and everything.

Attributions

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CHAPTER OVERVIEW

4: Biomes and the Biosphere

Learning Outcomes

- Describe the basic types of ecosystems on Earth
- Differentiate between food chains and food webs and recognize the importance of each
- Describe how organisms acquire energy in a food web and in associated food chains
- Discuss the biogeochemical cycles of water, carbon, nitrogen, phosphorus, and sulfur
- Explain how human activities have impacted these cycles

Page 4.1: Terrestrial Biomes
Page 4.2: Aquatic Biomes
Page 4.3: Chapter Resources

Thumbnail image - The (a) Karner blue butterfly and (b) wild lupine live in oak-pine barren habitats in North America. This habitat is characterized by natural disturbance in the form of fire and nutrient-poor soils that are low in nitrogen—important factors in the distribution of the plants that live in this habitat. Researchers interested in ecosystem ecology study the importance of limited resources in this ecosystem and the movement of resources (such as nutrients) through the biotic and abiotic portions of the ecosystem. Researchers also examine how organisms have adapted to their ecosystem. (credit: USFWS)

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Page 4.1: Terrestrial Biomes

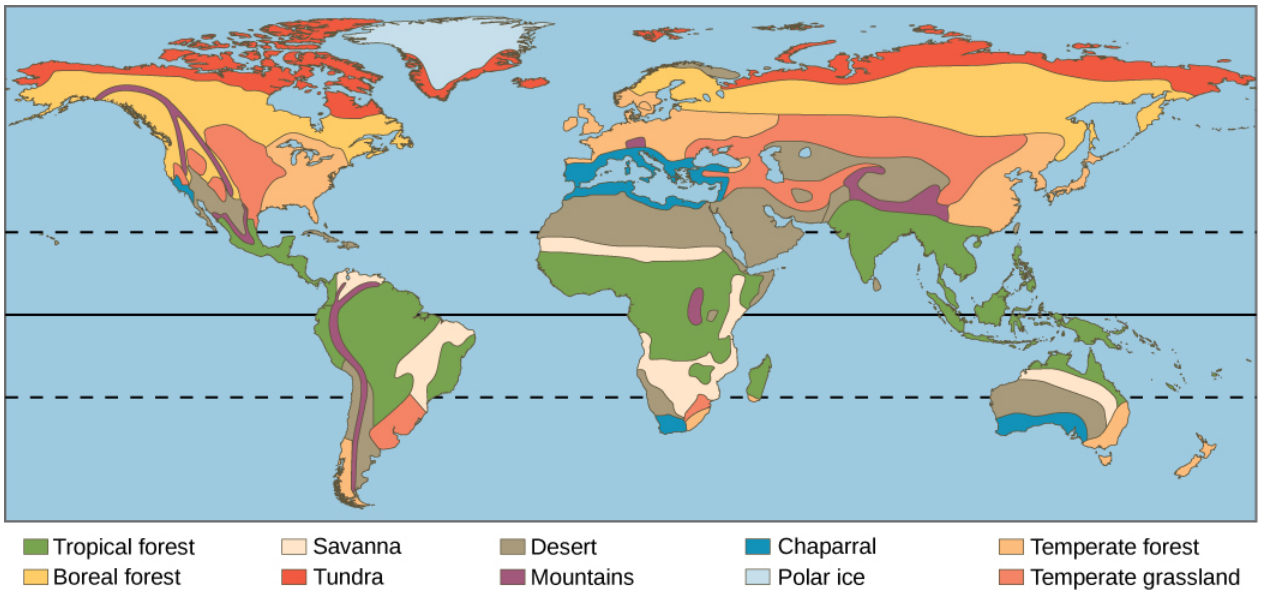


Figure $Page4.1.1$***. Each of the world's eight major biomes is distinguished by characteristic temperatures and amount of precipitation. Polar ice caps and mountains are also shown.***

There are eight major terrestrial biomes: tropical rainforests, savannas, subtropical deserts, chaparral, temperate grasslands, temperate forests, boreal forests, and Arctic tundra. **Biomes** are large-scale environments that are distinguished by characteristic temperature ranges and amounts of precipitation. These two variables affect the types of vegetation and animal life that can exist in those areas. Because each biome is defined by climate, the same biome can occur in geographically distinct areas with similar climates (Figures 1 and 2).

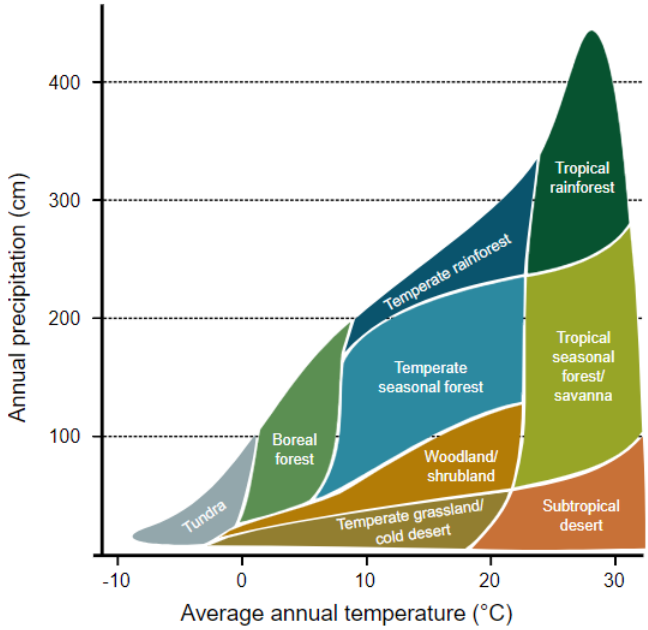


Figure $Page4.1.2$. Precipitation and temperature are the two most important climatic variables that determine the type of biome in a particular location. Credit: "Climate influence on terrestrial biome" by Navarras is in the Public Domain, CC0

Tropical rainforests are found in equatorial regions (Figure $Page4.1.1$) are the most biodiverse terrestrial biome. This biodiversity is under extraordinary threat primarily through logging and deforestation for agriculture. Tropical rainforests have also been described as nature's pharmacy because of the potential for new drugs that is largely hidden in the chemicals produced by the huge

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diversity of plants, animals, and other organisms. The vegetation is characterized by plants with spreading roots and broad leaves that fall off throughout the year, unlike the trees of deciduous forests that lose their leaves in one season.

The temperature and sunlight profiles of tropical rainforests are stable in comparison to other terrestrial biomes, with average temperatures ranging from 20°C to 34°C (68°F to 93°F). Month-to-month temperatures are relatively constant in tropical rainforests, in contrast to forests farther from the equator. This lack of temperature seasonality leads to year-round plant growth rather than just seasonal growth. In contrast to other ecosystems, a consistent daily amount of sunlight (11–12 hours per day year-round) provides more solar radiation and therefore more opportunity for primary productivity.

The annual rainfall in tropical rainforests ranges from 125 to 660 cm (50–200 in) with considerable seasonal variation. Tropical rainforests have wet months in which there can be more than 30 cm (11–12 in) of precipitation, as well as dry months in which there are fewer than 10 cm (3.5 in) of rainfall. However, the driest month of a tropical rainforest can still exceed the *annual* rainfall of some other biomes, such as deserts.Tropical rainforests have high net primary productivity because the annual temperatures and precipitation values support rapid plant growth. However, the high amounts of rainfall leaches nutrients from the soils of these forests.



Figure $Page4.1.3$. Species diversity is very high in tropical wet forests, such as these forests of Madre de Dios, Peru, near the Amazon River. (credit: Roosevelt Garcia)

Tropical rainforests are characterized by vertical layering of vegetation and the formation of distinct habitats for animals within each layer. On the forest floor is a sparse layer of plants and decaying plant matter. Above that is an understory of short, shrubby foliage. A layer of trees rises above this understory and is topped by a closed upper canopy—the uppermost overhead layer of branches and leaves. Some additional trees emerge through this closed upper canopy. These layers provide diverse and complex habitats for the variety of plants, animals, and other organisms. Many species of animals use the variety of plants and the complex structure of the tropical wet forests for food and shelter. Some organisms live several meters above ground, rarely descending to the forest floor.



Figure *Page4.1.4. A MinuteEarth video about how trees create rainfall, and vice versa.*



Figure *Page4.1.5*. Although savannas are dominated by grasses, small woodlands, such as this one in Mount Archer National Park in Queensland, Australia, may dot the landscape. (credit: "Ethel Aardvark"/Wikimedia Commons)

Subtropical deserts exist between 15° and 30° north and south latitude and are centered on the Tropic of Cancer and the Tropic of Capricorn (Figure *Page4.1.6* below). Deserts are frequently located on the downwind or lee side of mountain ranges, which create a rain shadow after prevailing winds drop their water content on the mountains. This is typical of the North American deserts, such as the Mohave and Sonoran deserts. Deserts in other regions, such as the Sahara Desert in northern Africa or the Namib Desert in southwestern Africa are dry because of the high-pressure, dry air descending at those latitudes. Subtropical deserts are very dry; evaporation typically exceeds precipitation. Subtropical hot deserts can have daytime soil surface temperatures above 60°C (140°F) and nighttime temperatures approaching 0°C (32°F). Subtropical deserts are characterized by low annual precipitation of fewer than 30 cm (12 in) with little monthly variation and lack of predictability in rainfall. Some years may receive tiny amounts of rainfall, while others receive more. In some cases, the annual rainfall can be as low as 2 cm (0.8 in) in subtropical deserts located in central Australia ("the Outback") and northern Africa.



Figure *Page4.1.6. A MinuteEarth video about the global climate patterns which lead to subtropical deserts.*

The low species diversity of this biome is closely related to its low and unpredictable precipitation. Despite the relatively low diversity, desert species exhibit fascinating adaptations to the harshness of their environment. Very dry deserts lack perennial vegetation that lives from one year to the next; instead, many plants are annuals that grow quickly and reproduce when rainfall does occur, then they die. Perennial plants in deserts are characterized by adaptations that conserve water: deep roots, reduced foliage, and water-storing stems (Figure *Page*4.1.6 below). Seed plants in the desert produce seeds that can lie dormant for extended periods between rains. Most animal life in subtropical deserts has adapted to a nocturnal life, spending the hot daytime hours beneath the ground. The Namib Desert is the oldest on the planet, and has probably been dry for more than 55 million years. It supports a number of endemic species (species found only there) because of this great age. For example, the unusual gymnosperm *Welwitschia mirabilis*is the only extant species of an entire order of plants. There are also five species of reptiles considered endemic to the Namib.

In addition to subtropical deserts there are **cold deserts** that experience freezing temperatures during the winter and any precipitation is in the form of snowfall. The largest of these deserts are the Gobi Desert in northern China and southern Mongolia, the Taklimakan Desert in western China, the Turkestan Desert, and the Great Basin Desert of the United States.



Figure *Page*4.1.7. Many desert plants have tiny leaves or no leaves at all to reduce water loss. The leaves of ocotillo, shown here in the Chihuahuan Desert in Big Bend National Park, Texas, appear only after rainfall and then are shed. (credit “bare ocotillo”: “Leaflet”/Wikimedia Commons)

The **chaparral** is also called scrub forest and is found in California, along the Mediterranean Sea, and along the southern coast of Australia (Figure *Page*4.1.7 below). The annual rainfall in this biome ranges from 65 cm to 75 cm (25.6–29.5 in) and the majority of the rain falls in the winter. Summers are very dry and many chaparral plants are dormant during the summertime. The chaparral vegetation is dominated by shrubs and is adapted to periodic fires, with some plants producing seeds that germinate only after a hot fire. The ashes left behind after a fire are rich in nutrients like nitrogen and fertilize the soil, promoting plant regrowth. Fire is a natural part of the maintenance of this biome.

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Figure $Page4.1.8$. The chaparral is dominated by shrubs. (credit: Miguel Vieira)

Temperate grasslands are found throughout central North America, where they are also known as prairies, and in Eurasia, where they are known as steppes (Figure $Page4.1.8$ below). Temperate grasslands have pronounced annual fluctuations in temperature with hot summers and cold winters. The annual temperature variation produces specific growing seasons for plants. Plant growth is possible when temperatures are warm enough to sustain plant growth, which occurs in the spring, summer, and fall.

Annual precipitation ranges from 25.4 cm to 88.9 cm (10–35 in). Temperate grasslands have few trees except for those found growing along rivers or streams. The dominant vegetation tends to consist of grasses. The treeless condition is maintained by low precipitation, frequent fires, and grazing. The vegetation is very dense and the soils are fertile because the subsurface of the soil is packed with the roots and rhizomes (underground stems) of these grasses. The roots and rhizomes act to anchor plants into the ground and replenish the organic material (humus) in the soil when they die and decay.

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Figure $Page4.1.9$. The American bison (*Bison bison), more commonly called the buffalo, is a grazing mammal that once populated American prairies in huge numbers. (credit: Jack Dykinga, USDA ARS)*

Fires, which are a natural disturbance in temperate grasslands, can be ignited by lightning strikes. It also appears that the lightning-caused fire regime in North American grasslands was enhanced by intentional burning by humans. When fire is suppressed in temperate grasslands, the vegetation eventually converts to scrub and dense forests. Often, the restoration or management of temperate grasslands requires the use of controlled burns to suppress the growth of trees and maintain the grasses.

Temperate forests are the most common biome in eastern North America, Western Europe, Eastern Asia, Chile, and New Zealand (Figure $Page4.1.9$ below). This biome is found throughout mid-latitude regions. Temperatures range between –30°C and 30°C (–22°F to 86°F) and drop to below freezing on an annual basis. These temperatures mean that temperate forests have defined growing seasons during the spring, summer, and early fall. Precipitation is relatively constant throughout the year and ranges between 75 cm and 150 cm (29.5–59 in).

Deciduous trees are the dominant plant in this biome with fewer evergreen conifers. Deciduous trees lose their leaves each fall and remain leafless in the winter. Thus, little photosynthesis occurs during the dormant winter period. Each spring, new leaves appear as temperature increases. Because of the dormant period, the net primary productivity of temperate forests is less than that of tropical rainforests. In addition, temperate forests show far less diversity of tree species than tropical rainforest biomes.

The trees of the temperate forests leaf out and shade much of the ground. However, more sunlight reaches the ground in this biome than in tropical rainforests because trees in temperate forests do not grow as tall as the trees in tropical rainforests. The soils of the temperate forests are rich in inorganic and organic nutrients compared to tropical rainforests. This is because of the thick layer of leaf litter on forest floors and reduced leaching of nutrients by rainfall. As this leaf litter decays, nutrients are returned to the soil. The leaf litter also protects soil from erosion, insulates the ground, and provides habitats for invertebrates and their predators.

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Figure $Page 4.1.10$. Deciduous trees are the dominant plant in the temperate forest. (credit: Oliver Herold)

The **boreal forest,** also known as **taiga** or **coniferous forest**, is found roughly between $50^{o}$and 60° north latitude across most of Canada, Alaska, Russia, and northern Europe (Figure $Page 4.1.10$ below). Boreal forests are also found above a certain elevation (and below high elevations where trees cannot grow) in mountain ranges throughout the Northern Hemisphere. This biome has cold, dry winters and short, cool, wet summers. The annual precipitation is from 40 cm to 100 cm (15.7–39 in) and usually takes the form of snow; relatively little evaporation occurs because of the cool temperatures.

The long and cold winters in the boreal forest have led to the predominance of cold-tolerant cone-bearing plants. These are evergreen coniferous trees like pines, spruce, and fir, which retain their needle-shaped leaves year-round. Evergreen trees can photosynthesize earlier in the spring than deciduous trees because less energy from the Sun is required to warm a needle-like leaf than a broad leaf. Evergreen trees grow faster than deciduous trees in the boreal forest. In addition, soils in boreal forest regions tend to be acidic with little available nitrogen. Leaves are a nitrogen-rich structure and deciduous trees must produce a new set of these nitrogen-rich structures each year. Therefore, coniferous trees that retain nitrogen-rich needles in a nitrogen limiting environment may have had a competitive advantage over the broad-leafed deciduous trees.

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Figure *Page*4.1.11. The boreal forest (taiga) has low lying plants and conifer trees. (credit: L.B. Brubaker, NOAA)

The net primary productivity of boreal forests is lower than that of temperate forests and tropical wet forests. The aboveground biomass of boreal forests is high because these slow-growing tree species are long-lived and accumulate standing biomass over time. Species diversity is less than that seen in temperate forests and tropical rainforests. Boreal forests lack the layered forest structure seen in tropical rainforests or, to a lesser degree, temperate forests. The structure of a boreal forest is often only a tree layer and a ground layer. When conifer needles are dropped, they decompose more slowly than broad leaves; therefore, fewer nutrients are returned to the soil to fuel plant growth.

The Arctic **tundra** lies north of the subarctic boreal forests and is located throughout the Arctic regions of the Northern Hemisphere. Tundra also exists at elevations above the tree line on mountains. The average winter temperature is –34°C (–29.2°F) and the average summer temperature is 3°C–12°C (37°F –52°F). Plants in the Arctic tundra have a short growing season of approximately 50–60 days. However, during this time, there are almost 24 hours of daylight and plant growth is rapid. The annual precipitation of the Arctic tundra is low (15–25 cm or 6–10 in) with little annual variation in precipitation. And, as in the boreal forests, there is little evaporation because of the cold temperatures.



Figure *Page*4.1.12. Low-growing plants such lichen and grasses are common in tundra. Credit: *Nunavut tundra by Flickr: My Nunavut is licensed under CC BY 2.0*

Plants in the Arctic tundra are generally low to the ground and include low shrubs, grasses, lichens, and small flowering plants (Figure *Page*4.1.11 below). There is little species diversity, low net primary productivity, and low above-ground biomass. The soils

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of the Arctic tundra may remain in a perennially frozen state referred to as permafrost. The permafrost makes it impossible for roots to penetrate far into the soil and slows the decay of organic matter, which inhibits the release of nutrients from organic matter. The melting of the permafrost in the brief summer provides water for a burst of productivity while temperatures and long days permit it. During the growing season, the ground of the Arctic tundra can be completely covered with plants or lichens.

Suggested Supplementary Reading

HHMI. 2018. *Biome Viewer*. [Interactive Website]. Howard Hughes Medical Institute. <https://www.hhmi.org/biointeractive/biomeviewer>

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Page 4.2: Aquatic Biomes

Abiotic Factors Influencing Aquatic Biomes

Like terrestrial biomes, **aquatic biomes** are influenced by a series of abiotic factors. The aquatic medium—water— has different physical and chemical properties than air. Even if the water in a pond or other body of water is perfectly clear (there are no suspended particles), water still absorbs light. As one descends into a deep body of water, there will eventually be a depth which the sunlight cannot reach. While there are some abiotic and biotic factors in a terrestrial ecosystem that might obscure light (like fog, dust, or insect swarms), usually these are not permanent features of the environment. The importance of light in aquatic biomes is central to the communities of organisms found in both freshwater and marine ecosystems. In freshwater systems, stratification due to differences in density is perhaps the most critical abiotic factor and is related to the energy aspects of light. The thermal properties of water (rates of heating and cooling) are significant to the function of marine systems and have major impacts on global climate and weather patterns. Marine systems are also influenced by large-scale physical water movements, such as currents; these are less important in most freshwater lakes.

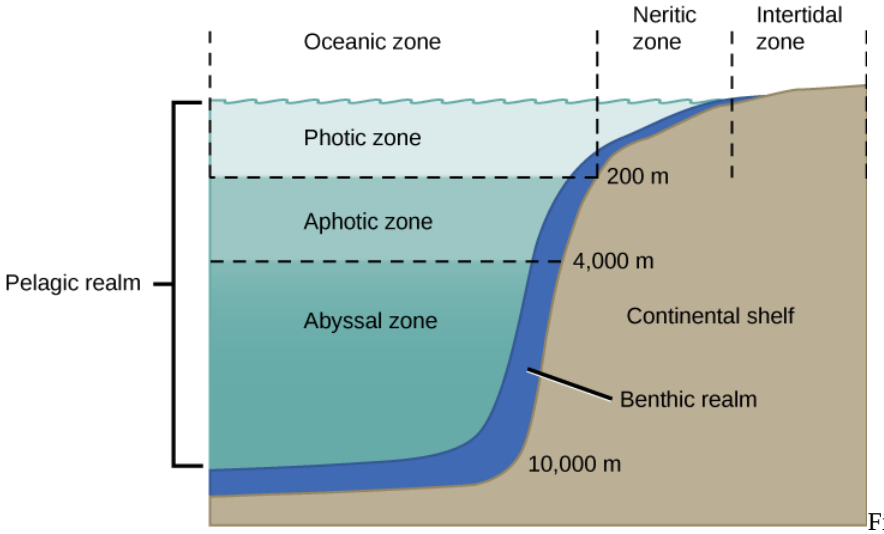


Figure $Page 4.2.1$. The ocean is divided into different zones based on water depth and distance from the shoreline.

The ocean is categorized by several areas or zones (Figure $Page 4.2.1$). All of the ocean's open water is referred to as the **pelagic zone**. The benthic zone extends along the ocean bottom from the shoreline to the deepest parts of the ocean floor. Within the pelagic realm is the **photic zone**, which is the portion of the ocean that light can penetrate (approximately 200 m or 650 ft). At depths greater than 200 m, light cannot penetrate; thus, this is referred to as the **aphotic zone**. The majority of the ocean is aphotic and lacks sufficient light for photosynthesis. The deepest part of the ocean, the Challenger Deep (in the Mariana Trench, located in the western Pacific Ocean), is about 11,000 m (about 6.8 mi) deep. To give some perspective on the depth of this trench, the ocean is, on average, 4267 m. These zones are relevant to freshwater lakes as well.

Marine Biomes

The ocean is the largest **marine biome**. It is a continuous body of salt water that is relatively uniform in chemical composition; it is a weak solution of mineral salts and decayed biological matter. Within the ocean, coral reefs are a second kind of marine biome. Estuaries, coastal areas where salt water and fresh water mix, form a third unique marine biome.

Ocean

The physical diversity of the ocean is a significant influence on plants, animals, and other organisms. The ocean is categorized into different zones based on how far light reaches into the water. Each zone has a distinct group of species adapted to the biotic and abiotic conditions particular to that zone.

The **intertidal zone**, which is the zone between high and low tide, is the oceanic region that is closest to land (Figure $Page 4.2.2$). Generally, most people think of this portion of the ocean as a sandy beach. In some cases, the intertidal zone is indeed a sandy

beach, but it can also be rocky or muddy. Organisms are exposed to air and sunlight at low tide and are underwater most of the time, especially during high tide. Therefore, living things that thrive in the intertidal zone are adapted to being dry for long periods of time. The shore of the intertidal zone is also repeatedly struck by waves, and the organisms found there are adapted to withstand damage from the pounding action of the waves (Figure $Page4.2.2$). The exoskeletons of shoreline crustaceans (such as the shore crab, *Carcinus maenas*) are tough and protect them from desiccation (drying out) and wave damage. Another consequence of the pounding waves is that few algae and plants establish themselves in the constantly moving rocks, sand, or mud.



Figure $Page4.2.2$. Sea urchins, mussel shells, and starfish are often found in the intertidal zone, shown here in Kachemak Bay, Alaska. (credit: NOAA)

The **neritic zone** (Figure $Page4.2.1$) extends from the intertidal zone to depths of about 200 m (or 650 ft) at the edge of the continental shelf. Because light can penetrate this depth, photosynthesis can occur. The water here contains silt and is well-oxygenated, low in pressure, and stable in temperature. Phytoplankton and floating *Sargassum* (a type of free-floating marine seaweed) provide a habitat for some sea life found in the neritic zone. Zooplankton, protists, small fishes, and shrimp are found in the neritic zone and are the base of the food chain for most of the world's fisheries.

Beyond the neritic zone is the open ocean area known as the **oceanic zone** (Figure $Page4.2.1$). Within the oceanic zone there is thermal stratification where warm and cold waters mix because of ocean currents. Abundant plankton serve as the base of the food chain for larger animals such as whales and dolphins. Nutrients are scarce and this is a relatively less productive part of the marine biome. When photosynthetic organisms and the protists and animals that feed on them die, their bodies fall to the bottom of the ocean where they remain. The majority of organisms in the aphotic zone include sea cucumbers (phylum Echinodermata) and other organisms that survive on the nutrients contained in the dead bodies of organisms in the photic zone.

The deepest part of the ocean is the **abyssal zone**, which is at depths of 4000 m or greater. The abyssal zone (Figure $Page4.2.1$) is very cold and has very high pressure, high oxygen content, and low nutrient content. There are a variety of invertebrates and fishes found in this zone, but the abyssal zone does not have plants because of the lack of light. Cracks in the Earth's crust called hydrothermal vents are found primarily in the abyssal zone. Around these vents chemosynthetic bacteria utilize the hydrogen sulfide and other minerals emitted as an energy source and serve as the base of the food chain found in the abyssal zone.

Beneath the water is the **benthic zone** (Figure $Page4.2.1$), which is comprised of sand, silt, and dead organisms. This is a nutrient-rich portion of the ocean because of the dead organisms that fall from the upper layers of the ocean. Because of this high level of nutrients, a diversity of sponges, sea anemones, marine worms, sea stars, fishes, and bacteria exist.

Coral Reefs

Coral reefs are characterized by high biodiversity and the structures created by invertebrates that live in warm, shallow waters within the photic zone of the ocean. They are mostly found within 30 degrees north and south of the equator. The Great Barrier Reef is a well-known reef system located several miles off the northeastern coast of Australia. The coral organisms (members of phylum Cnidaria) are colonies of saltwater polyps that secrete a calcium carbonate skeleton. These calcium-rich skeletons slowly accumulate, forming the underwater reef (Figure $Page4.2.3$).

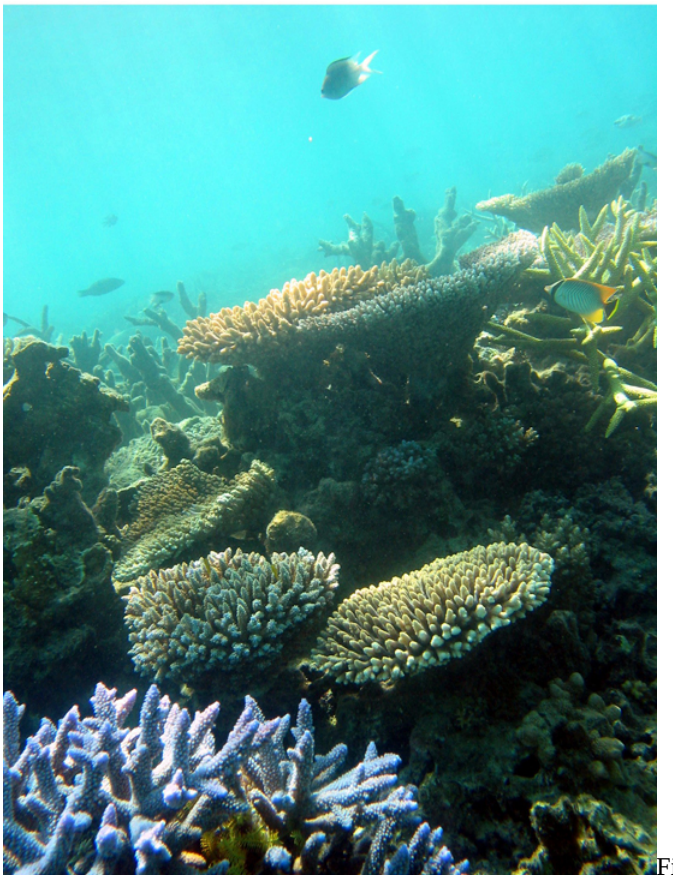


Figure $Page 4.2.3$. Coral reefs are formed by the calcium carbonate skeletons of coral organisms, which are marine invertebrates in the phylum Cnidaria. (credit: Terry Hughes)

Corals found in shallower waters (at a depth of approximately 60 m or about 200 ft) have a mutualistic relationship with photosynthetic unicellular algae. The relationship provides corals with the majority of the nutrition and the energy they require. The waters in which these corals live are nutritionally poor and, without this mutualism, it would not be possible for large corals to grow. Some corals living in deeper and colder water do not have a mutualistic relationship with algae; these corals attain energy and nutrients using stinging cells on their tentacles to capture prey. It is estimated that more than 4,000 fish species inhabit coral reefs. These fishes can feed on coral, other invertebrates, or the seaweed and algae that are associated with the coral.

Link to Learning: Watch this National Oceanic and Atmospheric Administration (NOAA) video to see marine ecologist Dr. Peter Etnoyer discusses his research on coral organisms.

EVOLUTION CONNECTION: Global Decline of Coral Reefs

It takes a long time to build a coral reef. The animals that create coral reefs have evolved over millions of years, continuing to slowly deposit the calcium carbonate that forms their characteristic ocean homes. Bathed in warm tropical waters, the coral animals and their symbiotic algal partners evolved to survive at the upper limit of ocean water temperature.

Together, climate change and human activity pose dual threats to the long-term survival of the world's coral reefs. As global warming due to fossil fuel emissions raises ocean temperatures, coral reefs are suffering. The excessive warmth causes the reefs to expel their symbiotic, food-producing algae, resulting in a phenomenon known as bleaching. When bleaching occurs, the reefs lose much of their characteristic color as the algae and the coral animals die if loss of the symbiotic zooxanthellae is prolonged.

Rising levels of atmospheric carbon dioxide further threaten the corals in other ways; as CO_2 dissolves in ocean waters, it lowers the pH and increases ocean acidity. As acidity increases, it interferes with the calcification that normally occurs as coral animals build their calcium carbonate homes.

When a coral reef begins to die, species diversity plummets as animals lose food and shelter. Coral reefs are also economically important tourist destinations, so the decline of coral reefs poses a serious threat to coastal economies.

Human population growth has damaged corals in other ways, too. As human coastal populations increase, the runoff of sediment and agricultural chemicals has increased, too, causing some of the once-clear tropical waters to become cloudy. At the same time, overfishing of popular fish species has allowed the predator species that eat corals to go unchecked.

Although a rise in global temperatures of 1–2˚C (a conservative scientific projection) in the coming decades may not seem large, it is very significant to this biome. When change occurs rapidly, species can become extinct before evolution leads to new adaptations. Many scientists believe that global warming, with its rapid (in terms of evolutionary time) and inexorable increases in temperature, is tipping the balance beyond the point at which many of the world's coral reefs can recover.

Estuaries: Where the Ocean Meets Fresh Water

Estuaries are biomes that occur where a source of fresh water, such as a river, meets the ocean. Therefore, both fresh water and salt water are found in the same vicinity; mixing results in a diluted (brackish) saltwater. Estuaries form protected areas where many of the young offspring of crustaceans, mollusks, and fish begin their lives. Salinity is a very important factor that influences the organisms and the adaptations of the organisms found in estuaries. The salinity of estuaries varies and is based on the rate of flow of its freshwater sources. Once or twice a day, high tides bring salt water into the estuary. Low tides occurring at the same frequency reverse the current of salt water.

The short-term and rapid variation in salinity due to the mixing of fresh water and salt water is a difficult physiological challenge for the plants and animals that inhabit estuaries. Many estuarine plant species are **halophytes**: plants that can tolerate salty conditions. Halophytic plants are adapted to deal with the salinity resulting from saltwater on their roots or from sea spray. In some halophytes, filters in the roots remove the salt from the water that the plant absorbs. Other plants are able to pump oxygen into their roots. Animals, such as mussels and clams (phylum Mollusca), have developed behavioral adaptations that expend a lot of energy to function in this rapidly changing environment. When these animals are exposed to low salinity, they stop feeding, close their shells, and switch from aerobic respiration (in which they use gills) to anaerobic respiration (a process that does not require oxygen). When high tide returns to the estuary, the salinity and oxygen content of the water increases, and these animals open their shells, begin feeding, and return to aerobic respiration.

Freshwater Biomes

Freshwater biomes include lakes and ponds (standing water) as well as rivers and streams (flowing water). They also include wetlands, which will be discussed later. Humans rely on freshwater biomes to provide aquatic resources for drinking water, crop irrigation, sanitation, and industry. These various roles and human benefits are referred to as ecosystem services. Lakes and ponds are found in terrestrial landscapes and are, therefore, connected with abiotic and biotic factors influencing these terrestrial biomes.

Lakes and Ponds

Lakes and ponds can range in area from a few square meters to thousands of square kilometers. Temperature is an important abiotic factor affecting living things found in lakes and ponds. In the summer, thermal stratification of lakes and ponds occurs when the upper layer of water is warmed by the sun and does not mix with deeper, cooler water. Light can penetrate within the photic zone of the lake or pond. **Phytoplankton** (small photosynthetic organisms such as algae and cyanobacteria that float in the water) are found here and carry out photosynthesis, providing the base of the food web of lakes and ponds. **Zooplankton** (very small animals that float in the water), such as rotifers and small crustaceans, consume these phytoplankton. At the bottom of lakes and ponds, bacteria in the aphotic zone break down dead organisms that sink to the bottom.



Figure $Page4.2.4$. The uncontrolled growth of algae in this lake has resulted in an algal bloom. (credit: Jeremy Nettleton)

Nitrogen and phosphorus are important limiting nutrients in lakes and ponds. Because of this, they are determining factors in the amount of phytoplankton growth in lakes and ponds. When there is a large input of nitrogen and phosphorus (from sewage and runoff from fertilized lawns and farms, for example), the growth of algae skyrockets, resulting in a large accumulation of algae called an **algal bloom**. Algal blooms (Figure $Page4.2.4$) can become so extensive that they reduce light penetration in water. As a result, the lake or pond becomes aphotic and photosynthetic plants rooted in the lake bottom cannot survive. When the algae die and decompose, severe oxygen depletion of the water occurs. Fishes and other organisms that require oxygen are then more likely to die, and resulting dead zones are found across the globe. Lake Erie and the Gulf of Mexico represent freshwater and marine habitats where phosphorus control and storm water runoff pose significant environmental challenges.

Rivers and Streams

Rivers and streams are continuously moving bodies of water that carry large amounts of water from the source, or headwater, to a lake or ocean. The largest rivers include the Nile River in Africa, the Amazon River in South America, and the Mississippi River in North America.



Figure $Page4.2.5$. Located in southern Florida, Everglades National Park is vast array of wetland environments, including sawgrass marshes, cypress swamps, and estuarine mangrove forests. Here, a great egret walks among cypress trees. (credit: NPS)

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Abiotic features of rivers and streams vary along the length of the river or stream. Streams begin at a point of origin referred to as source water. The source water is usually cold, low in nutrients, and clear. The channel (the width of the river or stream) is narrower than at any other place along the length of the river or stream. Because of this, the current is often faster here than at any other point of the river or stream.

The fast-moving water results in minimal silt accumulation at the bottom of the river or stream, therefore the water is clear. Photosynthesis here is mostly attributed to algae that are growing on rocks; the swift current inhibits the growth of phytoplankton. An additional input of energy can come from leaves or other organic material that falls into the river or stream from trees and other plants that border the water. When the leaves decompose, the organic material and nutrients in the leaves are returned to the water. Plants and animals have adapted to this fast-moving water. For instance, leeches (phylum Annelida) have elongated bodies and suckers on both ends. These suckers attach to the substrate, keeping the leech anchored in place. Freshwater trout species (phylum Chordata) are an important predator in these fast-moving rivers and streams.

As the river or stream flows away from the source, the width of the channel gradually widens and the current slows. This slow-moving water, caused by the gradient decrease and the volume increase as tributaries unite, has more sedimentation. Phytoplankton can also be suspended in slow-moving water. Therefore, the water will not be as clear as it is near the source. The water is also warmer. Worms (phylum Annelida) and insects (phylum Arthropoda) can be found burrowing into the mud. The higher order predator vertebrates (phylum Chordata) include waterfowl, frogs, and fishes. These predators must find food in these slow moving, sometimes murky, waters and, unlike the trout in the waters at the source, these vertebrates may not be able to use vision as their primary sense to find food. Instead, they are more likely to use taste or chemical cues to find prey.

Wetlands

Wetlands are environments in which the soil is either permanently or periodically saturated with water. Wetlands are different from lakes because wetlands are shallow bodies of water that may periodically dry out. Emergent vegetation consists of wetland plants that are rooted in the soil but have portions of leaves, stems, and flowers extending above the water's surface. There are several types of wetlands including marshes, swamps, bogs, mudflats, and salt marshes (Figure $Page4.2.5$).

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Page 4.3: Chapter Resources

Summary

Ecosystems exist underground, on land, at sea, and in the air. Organisms in an ecosystem acquire energy in a variety of ways, which is transferred between trophic levels as the energy flows from the base to the top of the food web, with energy being lost at each transfer. Mineral nutrients are cycled through ecosystems and their environment. Of particular importance are water, carbon, nitrogen, phosphorus, and sulfur. All of these cycles have major impacts on ecosystem structure and function. Ecosystems have been damaged by a variety of human activities that alter the natural biogeochemical cycles due to pollution, oil spills, and events causing global climate change. The health of the biosphere depends on understanding these cycles and how to protect the environment from irreversible damage. Earth has terrestrial and aquatic biomes. There are eight major terrestrial biomes: tropical rainforests, savannas, subtropical deserts, chaparral, temperate grasslands, temperate forests, boreal forests, and Arctic tundra. Temperature and precipitation, and variations in both, are key abiotic factors that shape the composition of animal and plant communities in terrestrial biomes. Sunlight is an important factor in bodies of water, especially those that are very deep, because of the role of photosynthesis in sustaining certain organisms. Other important factors include temperature, water movement, and salt content. Aquatic biomes include both freshwater and marine environments. Like terrestrial biomes, aquatic biomes are influenced by abiotic factors. In the case of aquatic biomes the abiotic factors include light, temperature, flow regime, and dissolved solids.

Review Questions

1. Secondary consumers would eat which one following?
   A. Producers
   B. Plants
   C. Herbivores
   D. Carnivores
   E. Tertiary consumers
2. If you are concerned about biomagnification of toxins, which one of the following would you most want to avoid eating?
   A. Tuna (tertiary consumer)
   B. Seaweed (producer)
   C. Urchin (primary consumer)
   D. Sculpin (secondary consumer)
   E. Any photoautotroph
3. Which one of the following is not a biogeochemical cycle?
   A. Energy cycle
   B. Nitrogen cycle
   C. Carbon cycle
   D. Phosphorus cycle
   E. Water cycle
4. Which one of the following would not increase the amount of water in the atmosphere?
   A. Evaporation
   B. Transpiration
   C. Sublimation
   D. Infiltration
   E. Evapotranspiration
5. Which one of the following processes would remove nitrates from contaminated water by converting it into nitrogen gas?
   A. Nitrification
   B. Nitrogen fixation
   C. Denitrification
   D. Assimilation
   E. Ammonification

6. What do deserts and chaparral have in common?
   A. Dry and hot summers
   B. Dominated by abundant evergreen shrubs
   C. Both can exist as either the hot or cold variety
   D. Very small amounts of rainfall consistently throughout the year
   E. Very low biodiversity
7. Which one of the following would most likely live within the benthic realm of the ocean?
   A. Squid
   B. Tuna
   C. Phytoplankton
   D. Marine worm
   E. Shark
8. What two variables most strongly contribute to the type of biome that exists in a particular area?
   A. Precipitation levels and temperature
   B. Type of producers and density of herbivores
   C. Amount of sunlight and annual rainfall
   D. Soil type and amount of O_2
   E. Distance from ocean and elevation
9. The conversion of nitrogen gas (N_2) into ammonia (NH_3) happens during which specific process?
   A. Ammonification
   B. Dentification
   C. Nitrification
   D. Nitrogenous cycling
   E. Nitrogen fixation
10. Use your knowledge of the relative energy content among trophic levels to answer the following question: A larger human population could be supported if all humans derived their food from which trophic level?
    A. Producers
    B. Primary consumers
    C. Secondary consumers
    D. Tertiary consumers
    E. Quaternary consumers

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

5: Community and Population Ecology

Learning Outcomes

- Describe how ecologists measure population size and density
- Describe three different patterns of population distribution
- Give examples of how the carrying capacity of a habitat may change
- Explain how humans have expanded the carrying capacity of their habitat
- Discuss the long-term implications of unchecked human population growth

Page 5.1: Population Demographics and Dynamics

Page 5.2: Population Growth and Regulation

Page 5.3: The Human Population

Page 5.4: Community Ecology

Page 5.5: Chapter Resources

Thumbnail image - Asian carp jump out of the water in response to electrofishing. The Asian carp in the inset photograph were harvested from the Little Calumet River in Illinois in May, 2010, using rotenone, a toxin often used as an insecticide, in an effort to learn more about the population of the species. (credit main image: modification of work by USGS; credit inset: modification of work by Lt. David French, USCG)

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Page 5.1: Population Demographics and Dynamics

Imagine sailing down a river in a small motorboat on a weekend afternoon; the water is smooth, and you are enjoying the sunshine and cool breeze when suddenly you are hit in the head by a 20-pound silver carp. This is a risk now on many rivers and canal systems in Illinois and Missouri because of the presence of Asian carp. This fish—actually a group of species including the silver, black, grass, and big head carp—has been farmed and eaten in China for over 1,000 years. It is one of the most important aquaculture food resources worldwide. In the United States, however, Asian carp is considered a dangerous invasive species that disrupts ecological community structure to the point of threatening native species. The effects of invasive species (such as the Asian carp, kudzu vine, predatory snakehead fish, and zebra mussel) are just one aspect of what ecologists study to understand how populations interact within ecological communities, and what impact natural and human-induced disturbances have on the characteristics of communities.

Populations are dynamic entities. Their size and composition fluctuate in response to numerous factors, including seasonal and yearly changes in the environment, natural disasters such as forest fires and volcanic eruptions, and competition for resources between and within species. The study of populations is called **demography.**

Population Size and Density

Populations are characterized by their population size (total number of individuals) and their population density (number of individuals per unit area). A population may have a large number of individuals that are distributed densely, or sparsely. There are also populations with small numbers of individuals that may be dense or very sparsely distributed in a local area. Population size can affect potential for adaptation because it affects the amount of genetic variation present in the population. Density can have effects on interactions within a population such as competition for food and the ability of individuals to find a mate. Smaller organisms tend to be more densely distributed than larger organisms (Figure $Page5.1.1$).

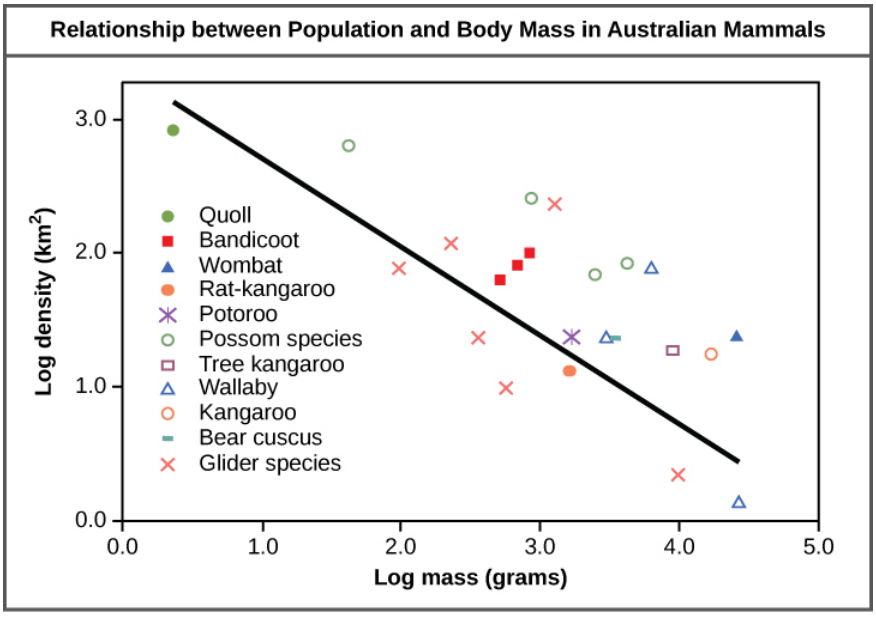


Figure $Page5.1.1$. Australian mammals show a typical inverse relationship between population density and body size. As this graph shows, population density typically decreases with increasing body size. Why do you think this is the case?

Estimating Population Size

The most accurate way to determine population size is to count all of the individuals within the area. However, this method is usually not logistically or economically feasible, especially when studying large areas. Thus, scientists usually study populations by sampling a representative portion of each habitat and use this sample to make inferences about the population as a whole. The methods used to sample populations to determine their size and density are typically tailored to the characteristics of the organism being studied. For immobile organisms such as plants, or for very small and slow-moving organisms, a quadrat may be used. A **quadrat** is a square structure that is randomly located on the ground and used to count the number of individuals that lie within its

boundaries. To obtain an accurate count using this method, the square must be placed at random locations within the habitat enough times to produce an accurate estimate.

For smaller mobile organisms, such as mammals, a technique called **mark and recapture** is often used. This method involves marking captured animals in and releasing them back into the environment to mix with the rest of the population. Later, a new sample is captured and scientists determine how many of the marked animals are in the new sample. This method assumes that the larger the population, the lower the percentage of marked organisms that will be recaptured since they will have mixed with more unmarked individuals. For example, if 80 field mice are captured, marked, and released into the forest, then a second trapping 100 field mice are captured and 20 of them are marked, the population size (N) can be determined using the following equation:

$$N = \frac{(\text{number marked first catch} \times \text{total number of second catch})}{\text{number marked second catch}} \quad \text{(Page 5.1.1)}$$

Using our example, the equation would be:

$$\frac{(80 \times 100)}{20} = 400 \quad \text{(Page 5.1.2)}$$

These results give us an estimate of 400 total individuals in the original population. The true number usually will be a bit different from this because of chance errors and possible bias caused by the sampling methods.

Species Distribution

In addition to measuring size and density, further information about a population can be obtained by looking at the distribution of the individuals throughout their range. A species distribution pattern is the distribution of individuals within a habitat at a particular point in time—broad categories of patterns are used to describe them.

Individuals within a population can be distributed at random, in groups, or equally spaced apart (more or less). These are known as **random, clumped, and uniform distribution patterns**, respectively (Figure $Page5.1.2$). Different distributions reflect important aspects of the biology of the species. They also affect the mathematical methods required to estimate population sizes. An example of random distribution occurs with dandelion and other plants that have wind-dispersed seeds that germinate wherever they happen to fall in favorable environments. A clumped distribution, may be seen in plants that drop their seeds straight to the ground, such as oak trees; it can also be seen in animals that live in social groups (schools of fish or herds of elephants). Uniform distribution is observed in plants that secrete substances inhibiting the growth of nearby individuals (such as the release of toxic chemicals by sage plants). It is also seen in territorial animal species, such as penguins that maintain a defined territory for nesting. The territorial defensive behaviors of each individual create a regular pattern of distribution of similar-sized territories and individuals within those territories. Thus, the distribution of the individuals within a population provides more information about how they interact with each other than does a simple density measurement. Just as lower density species might have more difficulty finding a mate, solitary species with a random distribution might have a similar difficulty when compared to social species clumped together in groups.



Figure $Page5.1.2$. Species may have a random, clumped, or uniform distribution. Plants such as (a) dandelions with wind-dispersed seeds tend to be randomly distributed. Animals such as (b) elephants that travel in groups exhibit a clumped distribution. Territorial birds such as (c) penguins tend to have a uniform distribution. (credit a: modification of work by Rosendahl; credit b: modification of work by Rebecca Wood; credit c: modification of work by Ben Tubby)

Life tables provide important information about the life history of an organism and the life expectancy of individuals at each age. They are modeled after actuarial tables used by the insurance industry for estimating human life expectancy. Life tables may include the probability of each age group dying before their next birthday, the percentage of surviving individuals dying at a particular age interval (their mortality rate, and their life expectancy at each interval. An example of a life table is shown in Table 1 from a study of Dall mountain sheep, a species native to northwestern North America. Notice that the population is divided into age intervals (column A).

As can be seen from the mortality rate data (column D), a high death rate occurred when the sheep were between six months and a year old, and then increased even more from 8 to 12 years old, after which there were few survivors. The data indicate that if a sheep in this population were to survive to age one, it could be expected to live another 7.7 years on average, as shown by the life-expectancy numbers in column E.

Table 1: Life Table of Dall Mountain Sheep

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Age interval (years)	Number dying in age interval out of 1000 born	Number surviving at beginning of age interval out of 1000 born	Mortality rate per 1000 alive at beginning of age interval	Life expectancy or mean lifetime remaining to those attaining age interval
0–0.5	54	1000	54.0	7.06
0.5–1	145	946	153.3	—
1–2	12	801	15.0	7.7
2–3	13	789	16.5	6.8
3–4	12	776	15.5	5.9
4–5	30	764	39.3	5.0
5–6	46	734	62.7	4.2
6–7	48	688	69.8	3.4
7–8	69	640	107.8	2.6
8–9	132	571	231.2	1.9
9–10	187	439	426.0	1.3
10–11	156	252	619.0	0.9
11–12	90	96	937.5	0.6
12–13	3	6	500.0	1.2
13–14	3	3	1000	0.7

Another tool used by population ecologists is a **survivorship curve**, which is a graph of the number of individuals surviving at each age interval versus time. These curves allow us to compare the life histories of different populations (Figure $Page5.1.3$). There are three types of survivorship curves. In a type I curve, mortality is low in the early and middle years and occurs mostly in older individuals. Organisms exhibiting a type I survivorship typically produce few offspring and provide good care to the offspring increasing the likelihood of their survival. Humans and most mammals exhibit a type I survivorship curve. In type II curves, mortality is relatively constant throughout the entire life span, and mortality is equally likely to occur at any point in the life span. Many bird populations provide examples of an intermediate or type II survivorship curve. In type III survivorship curves, early ages experience the highest mortality with much lower mortality rates for organisms that make it to advanced years. Type III organisms typically produce large numbers of offspring, but provide very little or no care for them. Trees and marine invertebrates exhibit a type III survivorship curve because very few of these organisms survive their younger years, but those that do make it to an old age are more likely to survive for a relatively long period of time.

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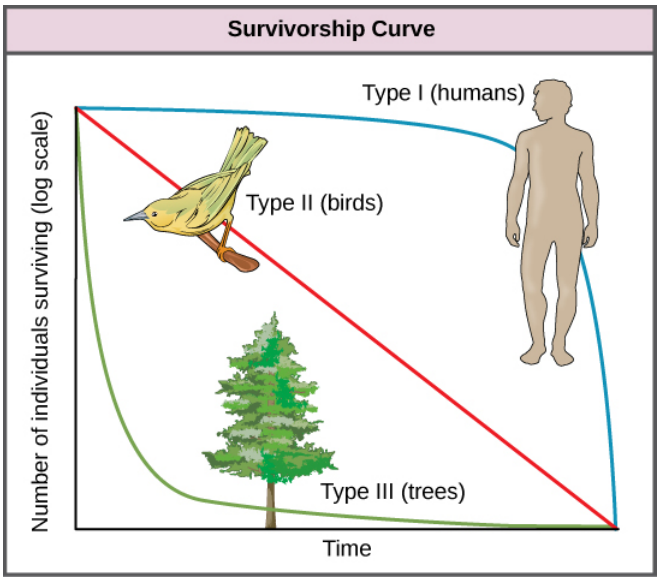


Figure $Page 5.1.3$. Survivorship curves show the distribution of individuals in a population according to age. Humans and most mammals have a Type I survivorship curve, because death primarily occurs in the older years. Birds have a Type II survivorship curve, as death at any age is equally probable. Trees have a Type III survivorship curve because very few survive the younger years, but after a certain age, individuals are much more likely to survive.

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Page 5.2: Population Growth and Regulation

Population ecologists make use of a variety of methods to model population dynamics. An accurate model should be able to describe the changes occurring in a population and predict future changes. The two simplest models of population growth use deterministic equations (equations that do not account for random events) to describe the rate of change in the size of a population over time. The first of these models, **exponential growth**, describes populations that increase in numbers without any limits to their growth. The second model, **logistic growth**, introduces limits to reproductive growth that become more intense as the population size increases. Neither model adequately describes natural populations, but they provide points of comparison.

Exponential Growth

Charles Darwin, in developing his theory of natural selection, was influenced by the English clergyman Thomas Malthus. Malthus published his book in 1798 stating that populations with abundant natural resources grow very rapidly. However, they limit further growth by depleting their resources. The early pattern of accelerating population size is called exponential growth (Figure $Page5.2.1$).

The best example of exponential growth in organisms is seen in bacteria. Bacteria are prokaryotes that reproduce quickly, about an hour for many species. If 1000 bacteria are placed in a large flask with an abundant supply of nutrients (so the nutrients will not become quickly depleted), the number of bacteria will have doubled from 1000 to 2000 after just an hour. In another hour, each of the 2000 bacteria will divide, producing 4000 bacteria. After the third hour, there should be 8000 bacteria in the flask. The important concept of exponential growth is that the growth rate—the number of organisms added in each reproductive generation—is itself increasing; that is, the population size is increasing at a greater and greater rate. After 24 of these cycles, the population would have increased from 1000 to more than 16 billion bacteria. When the population size, *N*, is plotted over time, a J-shaped growth curve is produced (Figure $Page5.2.1$).

The bacteria-in-a-flask example is not truly representative of the real world where resources are usually limited. However, when a species is introduced into a new habitat that it finds suitable, it may show exponential growth for a while. In the case of the bacteria in the flask, some bacteria will die during the experiment and thus not reproduce; therefore, the growth rate is lowered from a maximal rate in which there is no mortality.

Logistic Growth

Extended exponential growth is possible only when infinite natural resources are available; this is not the case in the real world. Charles Darwin recognized this fact in his description of the “struggle for existence,” which states that individuals will compete, with members of their own or other species, for limited resources. The successful ones are more likely to survive and pass on the traits that made them successful to the next generation at a greater rate (natural selection). To model the reality of limited resources, population ecologists developed the logistic growth model.

Carrying Capacity and the Logistic Model

In the real world, with its limited resources, exponential growth cannot continue indefinitely. Exponential growth may occur in environments where there are few individuals and plentiful resources, but when the number of individuals gets large enough, resources will be depleted and the growth rate will slow down. Eventually, the growth rate will plateau or level off (Figure $Page5.2.1$). This population size, which is determined by the maximum population size that a particular environment can sustain, is called the **carrying capacity**, symbolized as *K*. In real populations, a growing population often overshoots its carrying capacity and the death rate increases beyond the birth rate causing the population size to decline back to the carrying capacity or below it. Most populations usually fluctuate around the carrying capacity in an undulating fashion rather than existing right at it.

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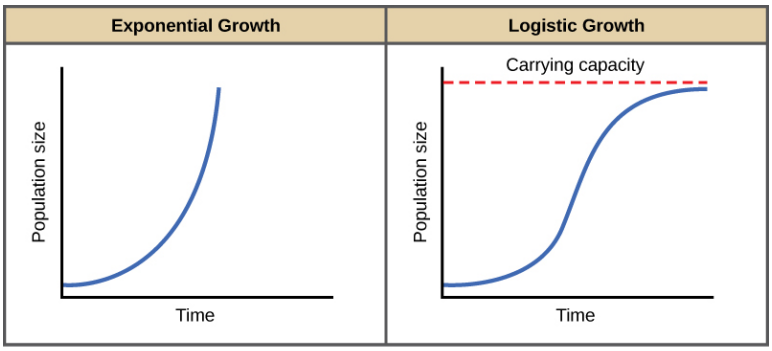


Figure $Page5.2.1$. When resources are unlimited, populations exhibit (a) exponential growth, shown in a J-shaped curve. When resources are limited, populations exhibit (b) logistic growth. In logistic growth, population expansion decreases as resources become scarce, and it levels off when the carrying capacity of the environment is reached. The logistic growth curve is S-shaped.

A graph of logistic growth yields the S-shaped curve (Figure $Page5.2.1$). It is a more realistic model of population growth than exponential growth. There are three different sections to an S-shaped curve. Initially, growth is exponential because there are few individuals and ample resources available. Then, as resources begin to become limited, the growth rate decreases. Finally, the growth rate levels off at the carrying capacity of the environment, with little change in population number over time.

Examples of Logistic Growth

Yeast, a unicellular fungus used to make bread and alcoholic beverages, exhibits the classical S-shaped curve when grown in a test tube (Figure $Page5.2.2$a). Its growth levels off as the population depletes the nutrients that are necessary for its growth. In the real world, however, there are variations to this idealized curve. Examples in wild populations include sheep and harbor seals (Figure $Page5.2.2$b). In both examples, the population size exceeds the carrying capacity for short periods of time and then falls below the carrying capacity afterwards. This fluctuation in population size continues to occur as the population oscillates around its carrying capacity. Still, even with this oscillation the logistic model is confirmed.

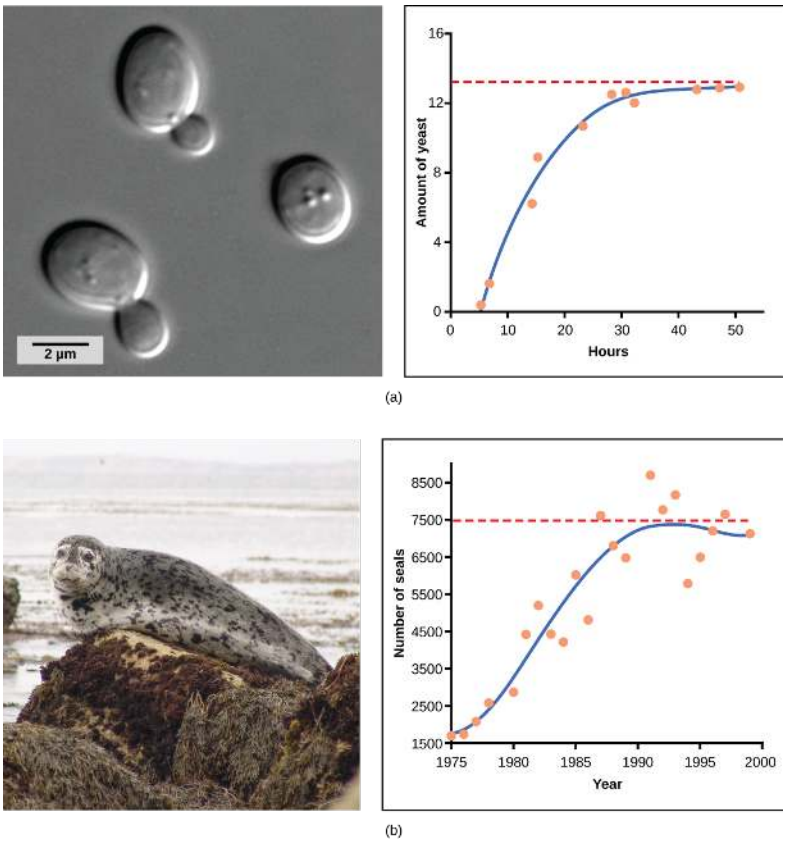


Figure $Page5.2.2$. (a) Yeast grown in ideal conditions in a test tube shows a classical S-shaped logistic growth curve, whereas (b) a natural population of seals shows real-world fluctuation. The yeast is visualized using differential interference contrast light micrography. (credit a: scale-bar data from Matt Russell)

Population Dynamics and Regulation

The logistic model of population growth, while valid in many natural populations and a useful model, is a simplification of real-world population dynamics. Implicit in the model is that the carrying capacity of the environment does not change, which is not the case. The carrying capacity varies annually. For example, some summers are hot and dry whereas others are cold and wet; in many areas, the carrying capacity during the winter is much lower than it is during the summer. Also, natural events such as earthquakes, volcanoes, and fires can alter an environment and hence its carrying capacity. Additionally, populations do not usually exist in isolation. They share the environment with other species, competing with them for the same resources (interspecific competition). These factors are also important to understanding how a specific population will grow.

Why Did the Woolly Mammoth Go Extinct?

Most populations of woolly mammoths went extinct about 10,000 years ago, soon after paleontologists believe humans began to colonize North America and northern Eurasia (Figure $Page5.2.3$). A mammoth population survived on Wrangel Island, in the East Siberian Sea, and was isolated from human contact until as recently as 1700 BC. We know a lot about these animals from carcasses found frozen in the ice of Siberia and other northern regions.

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(a)



(b)



(c)

Figure *Page*5.2.3. The three images include: (a) 1916 mural of a mammoth herd from the American Museum of Natural History, (b) the only stuffed mammoth in the world is in the Museum of Zoology located in St. Petersburg, Russia, and (c) a one-month-old baby mammoth, named Lyuba, discovered in Siberia in 2007. (credit a: modification of work by Charles R. Knight; credit b: modification of work by "Tanapon"/Flickr; credit c: modification of work by Matt Howry)

It is commonly thought that climate change and human hunting led to their extinction. A 2008 study estimated that climate change reduced the mammoth's range from 3,000,000 square miles 42,000 years ago to 310,000 square miles 6,000 years ago.[2] Through archaeological evidence of kill sites, it is also well documented that humans hunted these animals. A 2012 study concluded that no single factor was exclusively responsible for the extinction of these magnificent creatures.[3] In addition to climate change and reduction of habitat, scientists demonstrated another important factor in the mammoth's extinction was the migration of human hunters across the Bering Strait to North America during the last ice age 20,000 years ago.

The maintenance of stable populations was and is very complex, with many interacting factors determining the outcome. It is important to remember that humans are also part of nature. Once we contributed to a species' decline using primitive hunting technology only.

Demographic-Based Population Models

Population ecologists have hypothesized that suites of characteristics may evolve in species that lead to particular adaptations to their environments. These adaptations impact the kind of population growth their species experience. Life history characteristics such as birth rates, age at first reproduction, the numbers of offspring, and even death rates evolve just like anatomy or behavior, leading to adaptations that affect population growth. Population ecologists have described a continuum of life-history "strategies" with *K*-selected species on one end and *r*-selected species on the other. ***K*-selected species** are adapted to stable, predictable environments. Populations of *K*-selected species tend to exist close to their carrying capacity. These species tend to have larger, but fewer, offspring and contribute large amounts of resources to each offspring. Elephants would be an example of a *K*-selected species. ***r*-selected species** are adapted to unstable and unpredictable environments. They have large numbers of small offspring. Animals that are *r*-selected do not provide a lot of resources or parental care to offspring, and the offspring are relatively self-

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sufficient at birth. Examples of *r*-selected species are marine invertebrates such as jellyfish and plants such as the dandelion. The two extreme strategies are at two ends of a continuum on which real species life histories will exist. In addition, life history strategies do not need to evolve as suites, but can evolve independently of each other, so each species may have some characteristics that trend toward one extreme or the other.

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Page 5.3: The Human Population

Concepts of animal population dynamics can be applied to human population growth. Humans are not unique in their ability to alter their environment. For example, beaver dams alter the stream environment where they are built. Humans, however, have the ability to alter their environment to increase its carrying capacity, sometimes to the detriment of other species. Earth's human population and their use of resources are growing rapidly, to the extent that some worry about the ability of Earth's environment to sustain its human population. Long-term exponential growth carries with it the potential risks of famine, disease, and large-scale death, as well as social consequences of crowding such as increased crime.

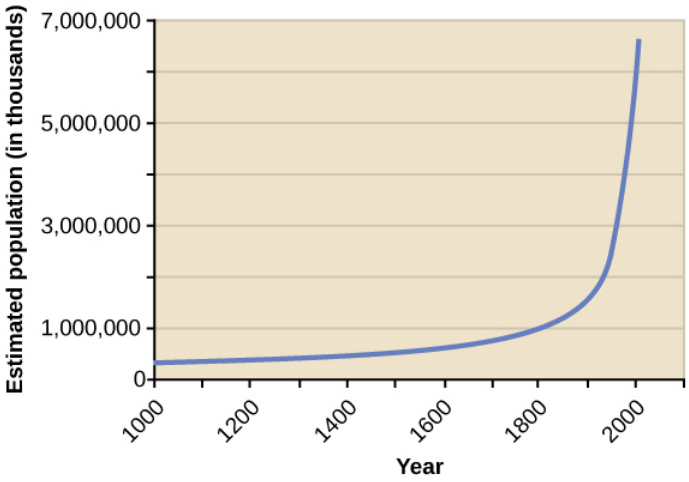


Figure $Page 5.3.1$. Human population growth since 1000 AD is exponential.

Human technology and particularly our harnessing of the energy contained in fossil fuels have caused unprecedented changes to Earth's environment, altering ecosystems to the point where some may be in danger of collapse. Changes on a global scale including depletion of the ozone layer, desertification and topsoil loss, and global climate change are caused by human activities.

Human Population Growth

The fundamental cause of the acceleration of growth rate for humans in the past 200 years has been the reduced death rate due to changes in public health and sanitation. Clean drinking water and proper disposal sewage has drastically improved health in developed nations. Also, medical innovations such as the use of antibiotics and vaccines have decreased the ability of infectious disease to limit human population growth. In the past, diseases such as the bubonic plaque of the fourteenth century killed between 30 and 60 percent of Europe's population and reduced the overall world population by as many as one hundred million people. Naturally, infectious disease continues to have an impact on human population growth, especially in poorer nations. For example, life expectancy in sub-Saharan Africa, which was increasing from 1950 to 1990, began to decline after 1985 largely as a result of HIV/AIDS mortality. The reduction in life expectancy caused by HIV/AIDS was estimated to be 7 years for 2005.

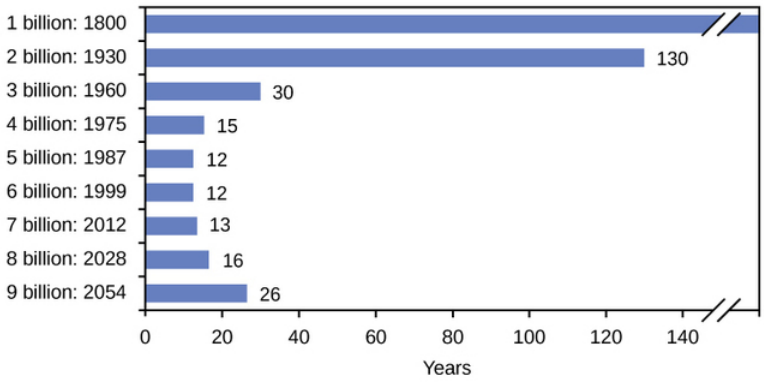


Figure $Page 5.3.2$. The time between the addition of each billion human beings to Earth decreases over time. (credit: modification of work by Ryan T. Cragun)

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Technological advances of the industrial age have also supported population growth through urbanization and advances in agriculture. These advances in technology were possible, in part, due to the exploitation of fossil fuels.

Age Structure, Population Growth, and Economic Development

The age structure of a population is an important factor in population dynamics. *Age structure* is the proportion of a population in different age classes. Models that incorporate age structure allow better prediction of population growth, plus the ability to associate this growth with the level of economic development in a region. Countries with rapid growth have a pyramidal shape in their age structure diagrams, showing a preponderance of younger individuals, many of whom are of reproductive age (Figure $Page5.3.3$).

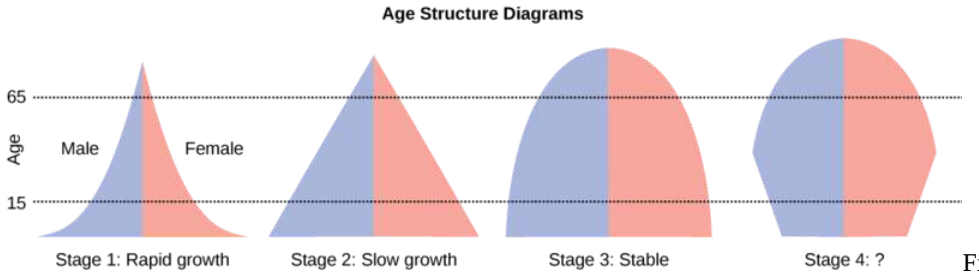


Figure $Page5.3.3$. Typical age structure diagrams are shown. The rapid growth diagram narrows to a point, indicating that the number of individuals decreases rapidly with age. In the slow growth model, the number of individuals decreases steadily with age. Stable population diagrams are rounded on the top, showing that the number of individuals per age group decreases gradually, and then increases for the older part of the population.

This pattern is most often observed in underdeveloped countries where individuals do not live to old age because of less-than-optimal living conditions, and there is a high birth rate. Age structures of areas with slow growth, including developed countries such as the United States, still have a pyramidal structure, but with many fewer young and reproductive-aged individuals and a greater proportion of older individuals. Other developed countries, such as Italy, have zero population growth. The age structure of these populations is more conical, with an even greater percentage of middle-aged and older individuals. The actual growth rates in different countries are shown in Figure $Page5.3.4$, with the highest rates tending to be in the less economically developed countries of Africa and Asia.

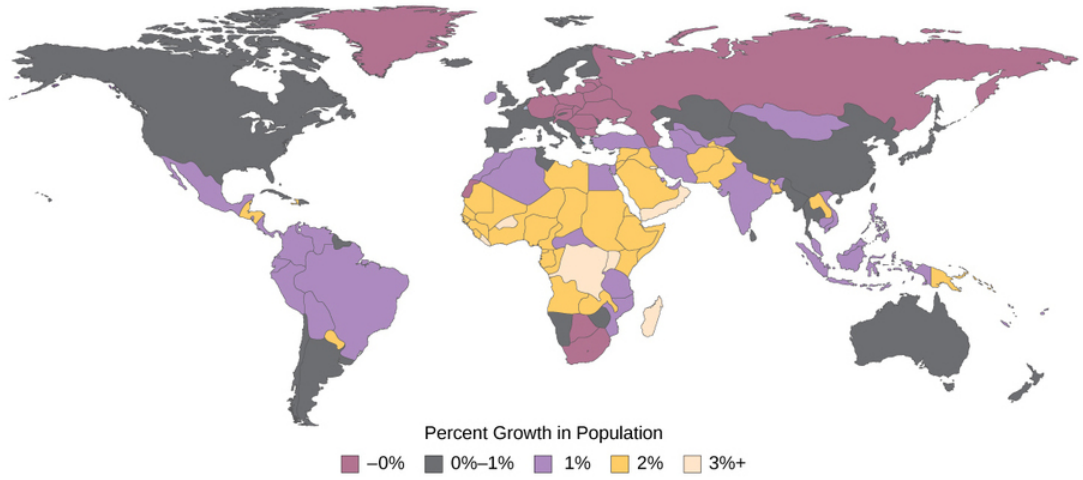


Figure $Page5.3.4$. The percent growth rate of population in different countries is shown. Notice that the highest growth is occurring in less economically developed countries in Africa and Asia.

Long-Term Consequences of Exponential Human Population Growth

Many dire predictions have been made about the world's population leading to a major crisis called the "population explosion." In the 1968 book *The Population Bomb*, biologist Paul R. Ehrlich wrote,

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> *"The battle to feed all of humanity is over. In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate."*

While these predictions obviously didn't bear fruit, the laws of exponential population growth are still in effect, and unchecked human population growth cannot continue indefinitely. Efforts to moderate population control led to the one-child policy in China, which imposes fines on urban couples who have more than one child. Due to the fact that some couples wish to have a male heir, many Chinese couples continue to have more than one child. The effectiveness of the policy in limiting overall population growth is controversial, as is the policy itself. Moreover, there are stories of female infanticide having occurred in some of the more rural areas of the country. Family planning education programs in other countries have had highly positive effects on limiting population growth rates and increasing standards of living.

In spite of population control policies, the human population continues to grow. The United Nations estimates the future world population size to be 11.2 billion people by the year 2100. There is no way to know whether human population growth will moderate to the point where the crisis described by Dr. Ehrlich will be averted. Another consequence of population growth is the change and degradation of the natural environment. Many countries have attempted to reduce the human impact on climate change by limiting their emission of greenhouse gases. However, a global climate change treaty remains elusive, and many underdeveloped countries trying to improve their economic condition may be less likely to agree with such provisions without compensation if it means slowing their economic development. Furthermore, the role of human activity in causing climate change has become a hotly debated socio-political issue in some developed countries, including the United States, despite the overwhelming scientific evidence. Thus, we enter the future with considerable uncertainty about our ability to curb human population growth and protect our environment to maintain the carrying capacity for the human species.

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Page 5.4: Community Ecology

Populations typically do not live in isolation from other species. Populations that interact within a given habitat form a **community**. The number of species occupying the same habitat and their relative abundance is known as the **diversity** of the community. Areas with low species diversity, such as the glaciers of Antarctica, still contain a wide variety of living organisms, whereas the diversity of tropical rainforests is so great that it cannot be accurately assessed. Scientists study ecology at the community level to understand how species interact with each other and compete for the same resources.

Predation and Herbivory

Perhaps the classical example of species interaction is the predator-prey relationship. The narrowest definition of *predation* describes individuals of one population that kill and then consume the individuals of another population. Population sizes of predators and prey in a community are not constant over time, and they may vary in cycles that appear to be related. The most often cited example of predator-prey population dynamics is seen in the cycling of the lynx (predator) and the snowshoe hare (prey), using 100 years of trapping data from North America (Figure $Page 5.4.1$). This cycling of predator and prey population sizes has a period of approximately ten years, with the predator population lagging one to two years behind the prey population. An apparent explanation for this pattern is that as the hare numbers increase, there is more food available for the lynx, allowing the lynx population to increase as well. When the lynx population grows to a threshold level, however, they kill so many hares that hare numbers begin to decline, followed by a decline in the lynx population because of scarcity of food. When the lynx population is low, the hare population size begins to increase due, in part, to low predation pressure, starting the cycle anew.

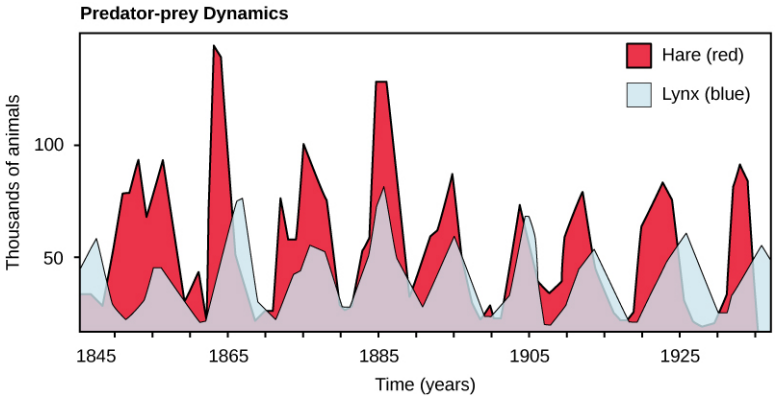


Figure $Page 5.4.1$. The cycling of snowshoe hare and lynx populations in Northern Ontario is an example of predator-prey dynamics.

Defense Mechanisms against Predation and Herbivory

Predation and predator avoidance are strong influenced by natural selection. Any heritable character that allows an individual of a prey population to better evade its predators will be represented in greater numbers in later generations. Likewise, traits that allow a predator to more efficiently locate and capture its prey will lead to a greater number of offspring and an increase in the commonness of the trait within the population. Such ecological relationships between specific populations lead to adaptations that are driven by reciprocal evolutionary responses in those populations. Species have evolved numerous mechanisms to escape predation (including **herbivory**, the consumption of plants for food). Defenses may be mechanical, chemical, physical, or behavioral.

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(a)



(b)

Figure $Page5.4.2$. The (a) honey locust tree uses thorns, a mechanical defense, against herbivores, while the (b) foxglove uses a chemical defense: toxins produces by the plant can cause nausea, vomiting, hallucinations, convulsions, or death when consumed. (credit a: modification of work by Huw Williams; credit b: modification of work by Philip Jägenstedt)

Mechanical defenses, such as the presence of armor in animals or thorns in plants, discourage predation and herbivory by discouraging physical contact (Figure $Page5.4.2$a). Many animals produce or obtain chemical defenses from plants and store them to prevent predation. Many plant species produce secondary plant compounds that serve no function for the plant except that they are toxic to animals and discourage consumption. For example, the foxglove produces several compounds, including digitalis, that are extremely toxic when eaten (Figure $Page5.4.2$b). (Biomedical scientists have repurposed the chemical produced by foxglove as a heart medication, which has saved lives for many decades.)

Many species use their body shape and coloration to avoid being detected by predators. The tropical walking stick is an insect with the coloration and body shape of a twig, which makes it very hard to see when it is stationary against a background of real twigs (Figure $Page5.4.3$a). In another example, the chameleon can change its color to match its surroundings (Figure $Page5.4.3$b).



(a)



(b)

Figure $Page5.4.3$. (a) The tropical walking stick and (b) the chameleon use their body shape and/or coloration to prevent detection by predators. (credit a: modification of work by Linda Tanner; credit b: modification of work by Frank Vassen)

Some species use coloration as a way of warning predators that they are distasteful or poisonous. For example, the monarch butterfly caterpillar sequesters poisons from its food (plants and milkweeds) to make itself poisonous or distasteful to potential predators. The caterpillar is bright yellow and black to advertise its toxicity. The caterpillar is also able to pass the sequestered toxins on to the adult monarch, which is also dramatically colored black and red as a warning to potential predators. Fire-bellied toads produce toxins that make them distasteful to their potential predators (Figure $Page5.4.4$). They have bright red or orange coloration on their bellies, which they display to a potential predator to advertise their poisonous nature and discourage an attack. Warning coloration only works if a predator uses eyesight to locate prey and can learn—a naïve predator must experience the negative consequences of eating one before it will avoid other similarly colored individuals.

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Figure $Page5.4.4$. The fire-bellied toad has bright coloration on its belly that serves to warn potential predators that it is toxic. (credit: modification of work by Roberto Verzo)

While some predators learn to avoid eating certain potential prey because of their coloration, other species have evolved mechanisms to mimic this coloration to avoid being eaten, even though they themselves may not be unpleasant to eat or contain toxic chemicals. In some cases of **mimicry**, a harmless species imitates the warning coloration of a harmful species. Assuming they share the same predators, this coloration then protects the harmless ones. Many insect species mimic the coloration of wasps, which are stinging, venomous insects, thereby discouraging predation (Figure $Page5.4.5$).



(a) (b)

Figure $Page5.4.5$. One form of mimicry is when a harmless species mimics the coloration of a harmful species, as is seen with the (a) wasp (Polistes sp.) and the (b) hoverfly (Syrphus sp.). (credit: modification of work by Tom Ings)

In other cases of mimicry, multiple species share the same warning coloration, but all of them actually have defenses. The commonness of the signal improves the compliance of all the potential predators. Figure $Page5.4.6$ shows a variety of foul-tasting butterflies with similar coloration.

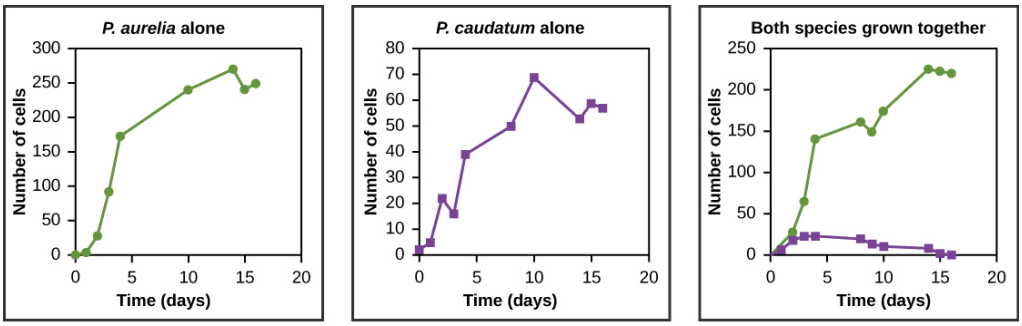


Figure $Page5.4.6$. Several unpleasant-tasting *Heliconiusbutterfly species share a similar color pattern with better-tasting varieties, an example of mimicry. (credit: Joron M, Papa R, Beltrán M, Chamberlain N, Mavárez J, et al.)*

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Competitive Exclusion Principle

Resources are often limited within a habitat and multiple species may compete to obtain them. Ecologists have come to understand that all species have an **ecological niche**: the unique set of resources used by a species, which includes its interactions with other species. The **competitive exclusion principle** states that two species cannot occupy the exact same niche in a habitat. In other words, different species cannot coexist in a community if they are competing for all the same resources. It is important to note that competition is bad for both competitors because it wastes energy. The competitive exclusion principle works because if there is competition between two species for the same resources, then natural selection will favor traits that lessen reliance on the shared resource, thus reducing competition. If either species is unable to evolve to reduce competition, then the species that most efficiently exploits the resource will drive the other species to extinction. An experimental example of this principle is shown in Figure $Page 5.4.7$ with two protozoan species: *Paramecium aurelia* and *Paramecium caudatum*. When grown individually in the laboratory, they both thrive. But when they are placed together in the same test tube (habitat), *P. aurelia* outcompetes *P. caudatum* for food, leading to the latter's eventual extinction.



(a) (b) (c)

Figure $Page 5.4.7$. *Paramecium aurelia and Paramecium caudatum grow well individually, but when they compete for the same resources, the P. aurelia outcompetes the P. caudatum.*

Symbiosis

Symbiotic relationships are close, long-term interactions between individuals of different species. Symbioses may be commensal, in which one species benefits while the other is neither harmed nor benefited; mutualistic, in which both species benefit; or parasitic, in which the interaction harms one species and benefits the other.



Figure $Page 5.4.8$. The southern masked-weaver is starting to make a nest in a tree in Zambezi Valley, Zambia. This is an example of a commensal relationship, in which one species (the bird) benefits, while the other (the tree) neither benefits nor is harmed. (credit: "Hanay"/Wikimedia Commons)

Commensalism occurs when one species benefits from a close prolonged interaction, while the other neither benefits or is harmed. Birds nesting in trees provide an example of a commensal relationship (Figure $Page 5.4.8$). The tree is not harmed by the presence of the nest among its branches. The nests are light and produce little strain on the structural integrity of the branch, and most of the leaves, which the tree uses to get energy by photosynthesis, are above the nest so they are unaffected. The bird, on the other hand, benefits greatly. If the bird had to nest in the open, its eggs and young would be vulnerable to predators. Many potential commensal

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relationships are difficult to identify because it is difficult to prove that one partner does not derive some benefit from the presence of the other.

A second type of symbiotic relationship is called **mutualism**, in which two species benefit from their interaction. For example, termites have a mutualistic relationship with protists that live in the insect's gut (Figure $Page5.4.9$a). The termite benefits from the ability of the protists to digest cellulose. However, the protists are able to digest cellulose only because of the presence of symbiotic bacteria within their cells that produce the cellulase enzyme. The termite itself cannot do this; without the protozoa, it would not be able to obtain energy from its food (cellulose from the wood it chews and eats). The protozoa benefit by having a protective environment and a constant supply of food from the wood chewing actions of the termite. In turn, the protists benefit from the enzymes provided by their bacterial endosymbionts, while the bacteria benefit from a doubly protective environment and a constant source of nutrients from two hosts. Lichen are a mutualistic relationship between a fungus and photosynthetic algae or cyanobacteria (Figure $Page5.4.9$b). The glucose produced by the algae provides nourishment for both organisms, whereas the physical structure of the lichen protects the algae from the elements and makes certain nutrients in the atmosphere more available to the algae. The algae of lichens can live independently given the right environment, but many of the fungal partners are unable to live on their own.



(a) (b)

Figure $Page5.4.9$. (a) Termites form a mutualistic relationship with symbiotic protozoa in their guts, which allow both organisms to obtain energy from the cellulose the termite consumes. (b) Lichen is a fungus that has symbiotic photosynthetic algae living in close association. (credit a: modification of work by Scott Bauer, USDA; credit b: modification of work by Cory Zanker)

A parasite is an organism that feeds off another without immediately killing the organism it is feeding on. In **parasitism**, the parasite benefits, but the organism being fed upon, the host, is harmed. The host is usually weakened by the parasite as it siphons resources the host would normally use to maintain itself. Parasites may kill their hosts, but there is usually selection to slow down this process to allow the parasite time to complete its reproductive cycle before it or its offspring are able to spread to another host. Parasitism is a form of predation.

The reproductive cycles of parasites are often very complex, sometimes requiring more than one host species. A tapeworm causes disease in humans when contaminated and under-cooked meat such as pork, fish, or beef is consumed (Figure $Page5.4.10$). The tapeworm can live inside the intestine of the host for several years, benefiting from the host's food, and it may grow to be over 50 feet long by adding segments. The parasite moves from one host species to a second host species in order to complete its life cycle.

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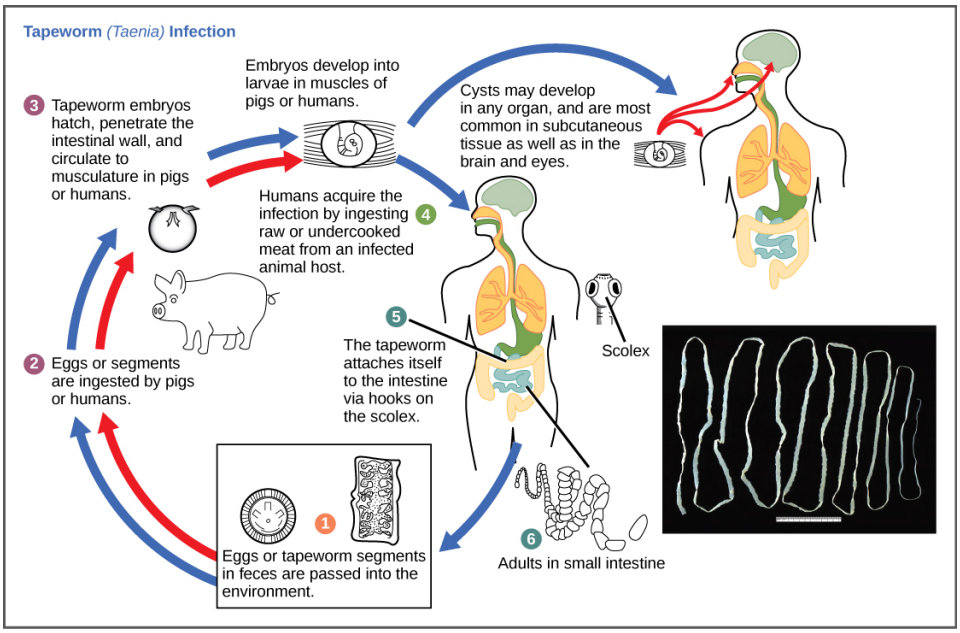


Figure $Page 5.4.10$. This diagram shows the life cycle of the tapeworm, a human worm parasite. (credit: modification of work by CDC)

Characteristics of Communities

Communities are complex systems that can be characterized by their structure (the number and size of populations and their interactions) and dynamics (how the members and their interactions change over time). Understanding community structure and dynamics allows us to minimize impacts on ecosystems and manage ecological communities we benefit from.

Ecologists have extensively studied one of the fundamental characteristics of communities: **biodiversity**. One measure of biodiversity used by ecologists is the number of different species in a particular area and their relative abundance. The area in question could be a habitat, a biome, or the entire biosphere. **Species richness** is the term used to describe the number of species living in a habitat or other unit. Species richness varies across the globe (Figure $Page 5.4.11$). Species richness is related to latitude: the greatest species richness occurs near the equator and the lowest richness occurs near the poles. The exact reasons for this are not clearly understood. Other factors besides latitude influence species richness as well. For example, ecologists studying islands found that biodiversity varies with island size and distance from the mainland.

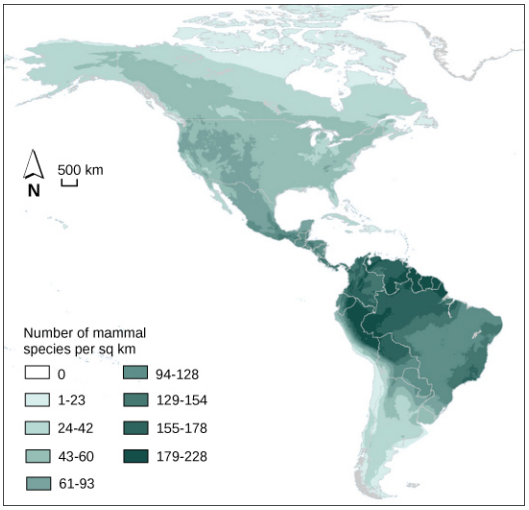


Figure $Page 5.4.11$. The greatest species richness for mammals in North America is associated in the equatorial latitudes. (credit: modification of work by NASA, CIESIN, Columbia University)

Relative abundance is the number individuals in a species relative to the total number of individuals in all species within a system. Foundation species, described below, often have the highest relative abundance of species.

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Foundation species are considered the “base” or “bedrock” of a community, having the greatest influence on its overall structure. They are often primary producers, and they are typically an abundant organism. For example, kelp, a species of brown algae, is a foundation species that forms the basis of the kelp forests off the coast of California.

Foundation species may physically modify the environment to produce and maintain habitats that benefit the other organisms that use them. Examples include the kelp described above or tree species found in a forest. The photosynthetic corals of the coral reef also provide structure by physically modifying the environment (Figure $Page5.4.12$). The exoskeletons of living and dead coral make up most of the reef structure, which protects many other species from waves and ocean currents.

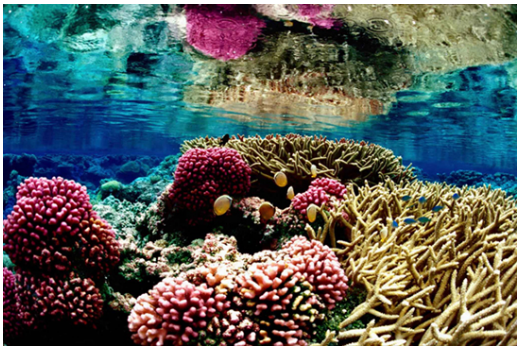


Figure $Page5.4.12$. Coral is the foundation species of coral reef ecosystems. (credit: Jim E. Maragos, USFWS)

A **keystone species** is one whose presence has inordinate influence in maintaining the prevalence of various species in an ecosystem, the ecological community’s structure, and sometimes its biodiversity. *Pisaster ochraceus*, the intertidal sea star, is a keystone species in the northwestern portion of the United States (Figure $Page5.4.13$). Studies have shown that when this organism is removed from communities, mussel populations (their natural prey) increase, which completely alters the species composition and reduces biodiversity. Another keystone species is the banded tetra, a fish in tropical streams, which supplies nearly all of the phosphorus, a necessary inorganic nutrient, to the rest of the community. The banded tetra feeds largely on insects from the terrestrial ecosystem and then excretes phosphorus into the aquatic ecosystem. The relationships between populations in the community, and possibly the biodiversity, would change dramatically if these fish were to become extinct.



Figure $Page5.4.13$. Sea stars are keystone species of the intertidal zone.

BIOLOGY IN ACTION

Invasive species are non-native organisms that, when introduced to an area out of its native range, alter the community they invade. In the United States, invasive species like the purple loosestrife (*Lythrum salicaria*) and the zebra mussel (*Dreissena polymorpha*) have drastically altered the ecosystems they invaded. Some well-known invasive animals include the emerald ash borer (*Agrilus planipennis*) and the European starling (*Sturnus vulgaris*). Whether enjoying a forest hike, taking a summer boat trip, or simply walking down an urban street, you have likely encountered an invasive species.

One of the many recent proliferations of an invasive species concerns the Asian carp in the United States. Asian carp were introduced to the United States in the 1970s by fisheries (commercial catfish ponds) and by sewage treatment facilities that used the fish’s excellent filter feeding abilities to clean their ponds of excess plankton. Some of the fish escaped, and by the 1980s they had colonized many waterways of the Mississippi River basin, including the Illinois and Missouri Rivers.

Voracious feeders and rapid reproducers, Asian carp may outcompete native species for food and could lead to their extinction. One species, the grass carp, feeds on phytoplankton and aquatic plants. It competes with native species for these resources and

alters nursery habitats for other fish by removing aquatic plants. In some parts of the Illinois River, Asian carp constitute 95 percent of the community's biomass. Although edible, the fish is bony and not desired in the United States.

The Great Lakes and their prized salmon and lake trout fisheries are being threatened by Asian carp. The carp are not yet present in the Great Lakes, and attempts are being made to prevent its access to the lakes through the Chicago Ship and Sanitary Canal, which is the only connection between the Mississippi River and Great Lakes basins. To prevent the Asian carp from leaving the canal, a series of electric barriers have been used to discourage their migration; however, the threat is significant enough that several states and Canada have sued to have the Chicago channel permanently cut off from Lake Michigan. Local and national politicians have weighed in on how to solve the problem. In general, governments have been ineffective in preventing or slowing the introduction of invasive species.

Community Dynamics

Community dynamics are the changes in community structure and composition over time, often following environmental disturbances such as volcanoes, earthquakes, storms, fires, and climate change. Communities with a relatively constant number of species are said to be at equilibrium. The equilibrium is dynamic with species identities and relationships changing over time, but maintaining relatively constant numbers. Following a disturbance, the community may or may not return to the equilibrium state.

Succession describes the sequential appearance and disappearance of species in a community over time after a severe disturbance. In primary succession, newly exposed or newly formed rock is colonized by living organisms. In **secondary succession**, a part of an ecosystem is disturbed and remnants of the previous community remain. In both cases, there is a sequential change in species until a more or less permanent community develops.

Primary Succession and Pioneer Species

Primary succession occurs when new land is formed, or when the soil and all life is removed from pre-existing land. An example of the former is the eruption of volcanoes on the Big Island of Hawaii, which results in lava that flows into the ocean and continually forms new land. From this process, approximately 32 acres of land are added to the Big Island each year. An example of pre-existing soil being removed is through the activity of glaciers. The massive weight of the glacier scours the landscape down to the bedrock as the glacier moves. This removes any original soil and leaves exposed rock once the glacier melts and retreats.



Figure $Page5.4.14$. During primary succession in lava on Maui, Hawaii, succulent plants are the pioneer species. (credit: Forest and Kim Starr)

In both cases, the ecosystem starts with bare rock that is devoid of life. New soil is slowly formed as weathering and other natural forces break down the rock and lead to the establishment of hearty organisms, such as lichens and some plants, which are collectively known as **pioneer species** (Figure $Page5.4.14$) because they are the first to appear. These species help to further break down the mineral-rich rock into soil where other, less hardy but more competitive species, such as grasses, shrubs, and trees, will grow and eventually replace the pioneer species. Over time the area will reach an equilibrium state, with a set of organisms quite different from the pioneer species.

Secondary succession

A classic example of secondary succession occurs in forests cleared by wildfire, or by clearcut logging (Figure $Page5.4.15$). Wildfires will burn most vegetation, and unless the animals can flee the area, they are killed. Their nutrients, however, are returned

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to the ground in the form of ash. Thus, although the community has been dramatically altered, there is a soil ecosystem present that provides a foundation for rapid recolonization.

Before the fire, the vegetation was dominated by tall trees with access to the major plant energy resource: sunlight. Their height gave them access to sunlight while also shading the ground and other low-lying species. After the fire, though, these trees are no longer dominant. Thus, the first plants to grow back are usually annual plants followed within a few years by quickly growing and spreading grasses and other pioneer species. Due, at least in part, to changes in the environment brought on by the growth of grasses and forbs, over many years, shrubs emerge along with small trees. These organisms are called intermediate species. Eventually, over 150 years or more, the forest will reach its equilibrium point and resemble the community before the fire. This equilibrium state is referred to as the **climax community**, which will remain until the next disturbance. The climax community is typically characteristic of a given climate and geology. Although the community in equilibrium looks the same once it is attained, the equilibrium is a dynamic one with constant changes in abundance and sometimes species identities.

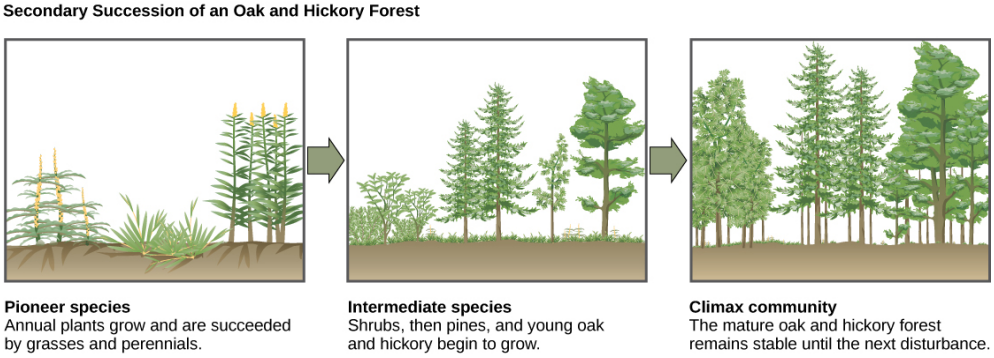


Figure $Page 5.4.15$. Secondary succession is seen in an oak and hickory forest after a forest fire. A sequence of the community present at three successive times at the same location is depicted.

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Page 5.5: Chapter Resources

Summary

Populations are individuals of a species that live in a particular habitat. Ecologists measure characteristics of populations: size, density, and distribution pattern. Life tables are useful to calculate life expectancies of individual population members. Survivorship curves show the number of individuals surviving at each age interval plotted versus time. Populations with unlimited resources grow exponentially—with an accelerating growth rate. When resources become limiting, populations follow a logistic growth curve in which population size will level off at the carrying capacity. Humans have increased their carrying capacity through technology, urbanization, and harnessing the energy of fossil fuels. Unchecked human population growth could have dire long-term effects on human welfare and Earth's ecosystems. Communities include all the different species living in a given area. The variety of these species is referred to as biodiversity. Species may form symbiotic relationships such as commensalism, mutualism, or parasitism. Community structure is described by its foundation and keystone species. Communities respond to environmental disturbances by succession: the predictable appearance of different types of plant species, until a stable community structure is established.

Review Questions

1. You are working as a biologist and perform the "mark and recapture" technique to estimate the number of endangered lemurs living within a particular habitat. You initially capture 37 lemurs, marking them all before releasing them. Two months later, you capture 49 lemurs, of which 11 are those originally captured and marked. What is the estimated size of the lemur population, rounded to the nearest whole number?

   A. 60
   B. 86
   C. 97
   D. 165
   E. 407

2. Which one of the following measuring techniques would best enable you to determine the distribution pattern of a population of zebra?

   A. Track how many and which individuals use a central watering hole
   B. Use a drone to capture aerial photographs of their habitat range
   C. Employ a camera trap in the middle of their habitat
   D. Use the mark-recapture method
   E. Collect and analyze DNA from hair samples collected at 2 locations

3. A species that you are studying has a type III survivorship curve. Which one of the following describes this type of curve?

   A. Survivorship rates are lowest during early parts of its lifecycle
   B. Survivorship rates are lowest during the late parts of its lifecycle
   C. Survivorship rates are highest during early parts of its lifecycle
   D. Survivorship rates are consistent through the lifecycle
   E. Survivorship rates are highest in the early and middle parts of its lifecycle

4. A population has unlimited resources and exhibits rapid and sustained population growth. This type of growth would be best described by which one of the following?

   A. Exponential
   B. Logistic
   C. Sigmoidal
   D. Parabolic
   E. Inverse

5. What single factor has most strongly contributed to the rapid population growth in the human population witnessed over the last 150 years?

   A. Increased fertility rates

B. Reduced death rates
C. Longer life spans
D. Economic growth
E. Increased morbidity

6. Which one of the following age groups would most likely to lead to rapid population growth in the future if it contained the greatest relative abundance within that population?

A. 0-15 years old
B. 16-30 years old
C. 31-45 years old
D. 46-60 years old
E. 61 years old and greater

7. Two species have the same ecological niche. If they lived in the same habitat, both would compete until one species became predominant and the other became locally extinct. This process is summarized by which one of the following?

A. Niche warfare
B. Competitive exclusion principle
C. Species selection principle
D. Exclusion through competition theorem
E. Exclusive ecological fractioning

8. Which form of symbiosis benefits one member of the interaction, but neither benefits nor harms the other member?

A. Parasitism
B. Commensalism
C. Sequentialism
D. Mutualism
E. Natural selection

9. Biologists examined the effects of reintroducing wolves into Yellowstone National Park of the United States. They found that by preying on elk, wolves altered the foraging behavior of the elk; the elk spent less time browsing near streambanks. This allowed the regrowth of important vegetation, which had large positive impacts on the ecosystem at large. When a relatively small number of individuals, like wolves, have disproportionate impacts on the ecosystem, they are referred to as a…

A. Foundation species
B. Portal species
C. Keystone species
D. Cornerstone species
E. Pivotal species

10. The 1980 volcanic explosion of Mt. St. Helens in the United States devasted the north side of the mountain and it's forests. The forests were demolished and replaced with volcanic debris that formed the new soil, free of any remnants of the previous ecosystem (such as seeds stored in the soil). Such an event would lead to which one of the following processes?

A. Primary succession
B. Secondary succession
C. Tertiary succession
D. Quaternary succession
E. Pioneering succession

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

6: Conventional and Sustainable Energy

Learning Outcomes

- Outline the history of human energy use
- Understand the challenges to continued reliance on fossil energy
- Outline environmental impacts of energy use
- Understand the global capacity for each non-renewable energy source
- Evaluate the different energy sources based on their environmental impact
- Understand the key factors in the growth of renewable energy sources

Page 6.1: Challenges and Impacts of Energy Use

Page 6.2: Non-Renewable Energy Sources

Page 6.3: Renewable Energy Sources

Page 6.4: Chapter Resources

Thumbnail image - Wind farm near Copenhagen, Denmark. In 2014 wind power met 39% of electricity demand in Denmark.

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Page 6.1: Challenges and Impacts of Energy Use

Energy for lighting, heating and cooling our buildings, manufacturing products, and powering our transportation systems comes from a variety of natural sources. The earth's core provides geothermal energy. The gravitational pull of moon and sun create tides. The sun emits light (electromagnetic radiation), which creates wind, powers the water (hydrologic) cycle, and enables photosynthesis. Plants, algae, and cyanobacteria utilize solar energy to grow and create biomass that can be burned and used for **biofuels**, such as wood, biodiesel, bioethanol. Over the course of millions of years, biomass from photosynthetic organisms can create energy-rich **fossil fuels** through the geologic process of burial and transformation through heat and pressure.

Each of these types of energy can be defined as **renewable** or **non-renewable.** Renewable energy sources can be replenished within human lifespans. Examples include solar, wind, and biomass energy. Non-renewable energy is finite and cannot be replenished within a human timescale. Examples include nuclear energy and fossil fuels, which take millions of years to form. All energy sources have and some environmental and health cost, and the distribution of energy is not equally distributed among all nations.

Environmental and Health Challenges of Energy Use

The environmental impacts of energy use on humans and the planet can happen anywhere during the life cycle of the energy source. The impacts begin with the extraction of the resource. They continue with the processing, purification or manufacture of the source; its transportation to place of energy generation, and ends with the disposal of waste generated during use.

Extraction of fossil fuels can be used as a case study because its use has significant impacts on the environment. As we mine deeper into mountains, farther out at sea, or farther into pristine habitats, we risk damaging fragile environments, and the results of accidents or natural disasters during extraction processes can be devastating. Fossils fuels are often located far from where they are utilized so they need to be transported by pipeline, tankers, rail or trucks. These all present the potential for accidents, leakage and spills. When transported by rail or truck energy must be expended and pollutants are generated. Processing of petroleum, gas and coal generates various types of emissions and wastes, as well as utilizes water resources. Production of energy at power plants results in air, water, and, often, waste emissions. Power plants are highly regulated in the Unites States by federal and state law under the Clean Air and Clean Water Acts, while nuclear power plants are regulated by the Nuclear Regulatory Commission.

Geopolitical Challenges of Fossil Fuels

The use of fossil fuels has allowed much of the global population to reach a higher standard of living. However, this dependence on fossil fuels results in many significant impacts on society. Our modern technologies and services, such as transportation and plastics depend in many ways on fossil fuels. If supplies become limited or extremely costly, our economies are vulnerable. If countries do not have fossil fuel reserves of their own, they incur even more risk. The United States has become more and more dependent on foreign oil since 1970 when our own oil production peaked. The United States imported over half of the crude oil and refined petroleum products that we consumed during 2009. Just over half of these imports came from the Western Hemisphere (Figure $Page 6.1.2$).

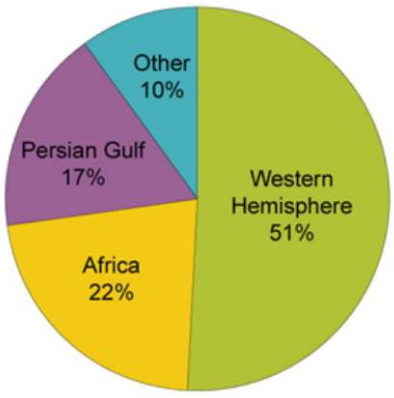


Figure illustrates that the United States imported over half of the crude oil and refined petroleum products that it consumed during 2009. Source: U.S. Energy Information Administration, Petroleum Supply Annual, 2009, preliminary data.

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The major holder of oil reserves is the **Organization of Petroleum Exporting Countries,** (OPEC) (Figure *Page*6.1.3). As of 2018, there were 15 member countries in OPEC: Algeria, Angola, Congo, Ecuador, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. OPEC attempts to influence the amount of oil available to the world by assigning a production quota to each member except Iraq, for which no quota is presently set.

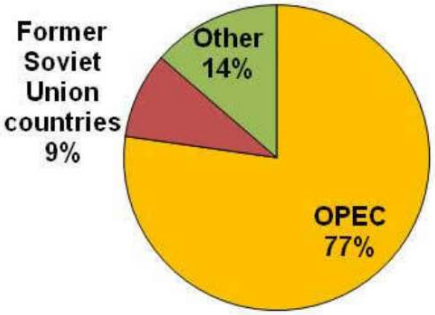


Figure *Page*6.1.3. Proven Oil Reserves Holders Pie chart shows proven oil reserves holders. Source: C. Klein-Banai using data from BP Statistical Review of World Energy (2010)

Overall compliance with these quotas is mixed since the individual countries make the actual production decisions. All of these countries have a national oil company but also allow international oil companies to operate within their borders. They can restrict the amounts of production by those oil companies. Therefore, the OPEC countries have a large influence on how much of world demand is met by OPEC and non-OPEC supply. A recent example of this is the price increases that occurred during the year 2011 after multiple popular uprisings in Arab countries, including Libya.

This pressure has lead the United States to developing policies that would reduce reliance on foreign oil such as developing additional domestic sources and obtaining it from non-Middle Eastern countries such as Canada, Mexico, Venezuela, and Nigeria. However, since fossil fuel reserves create jobs and provide dividends to investors, a lot is at stake in a nation that has oil reserves. Oil wealth may be shared with the country's inhabitants or retained by the oil companies and dictatorships, such as in Nigeria prior to the 1990s.

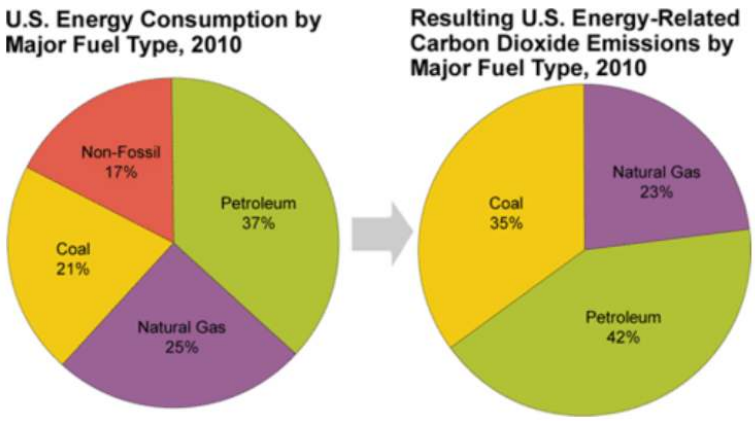


Figure *Page*6.1.4. Fuel Type and Carbon Emissions The two charts show the relationship between fuel type and carbon emissions for U.S. energy consumption in 2010. Source: U.S. Energy Information Administration

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Page 6.2: Non-Renewable Energy Sources

Fossil Fuels

Fossil fuels comes from the organic matter of plants, algae, and cyanobacteria that was buried, heated, and compressed under high pressure over millions of years. The process transformed the biomass of those organisms into the three types of fossil fuels: oil, coal, and natural gas.

Petroleum (oil)

Thirty seven percent of the world's energy consumption and 43% of the United States energy consumption comes from oil. Scientists and policy-makers often discuss the question of when the world will reach **peak oil production**, the point at which oil production is at its greatest and then declines. It is generally thought that peak oil will be reached by the middle of the 21st Century, although making such estimates is difficult because a lot of variables must be considered. Currently world reserves are 1.3 trillion barrels, or 45 years left at current level of production..

Environmental Impacts of Oil Extraction and Refining

Oil is usually found one to two miles (1.6 – 3.2 km) below the Earth's surface, whether that is on land or ocean. Once oil is found and extracted it must be refined, which separates and prepares the mix of crude oil into the different types for gas, diesel, tar, and asphalt. Oil refining is one of top sources of air pollution in the United States for volatile organic hydrocarbons and toxic emissions, and the single largest source of carcinogenic benzene. When petroleum is burned as gasoline or diesel, or to make electricity or to power boilers for heat, it produces a number of emissions that have a detrimental effect on the environment and human health:

- Carbon dioxide (CO_2) is a greenhouse gas and a source of climate change.
- Sulfur dioxide (SO_2) causes acid rain, which damages plants and animals that live in water, and it increases or causes respiratory illnesses and heart diseases, particularly in vulnerable populations like children and the elderly.
- Nitrous oxides (NO_x) and Volatile Organic Carbons (VOCs) contribute to ozone at ground level, which is an irritant and causes damage to the lungs.
- Particulate Matter (PM) produces hazy conditions in cities and scenic areas, and combines with ozone to contribute to asthma and chronic bronchitis, especially in children and the elderly. Very small, or "fine PM," is also thought to penetrate the respiratory system more deeply and cause emphysema and lung cancer.
- Lead can have severe health impacts, especially for children.

There are other domestic sources of oil that are being considered as conventional resources and are being depleted. These include **tar sands** – deposits of moist sand and clay with 1-2 percent bitumen (thick and heavy petroleum rich in carbon and poor in hydrogen). These are removed by strip mining (see section below on coal). Another source is **oil shale,** which is sedimentary rock filled with organic matter that can be processed to produce liquid petroleum. Extracted by strip mining or creating subsurface mines, oil shale can be burned directly like coal or baked in the presence of hydrogen to extract liquid petroleum. However, the net energy values are low and they are expensive to extract and process. Both of these resources have severe environmental impacts due to strip mining, carbon dioxide, methane and other air pollutants similar to other fossil fuels.

As the United States tries to extract more oil from its own dwindling resources, they are drilling even deeper into the earth and increasing the environmental risks. The largest United States oil spill to date began in April 2010 when an explosion occurred on Deepwater Horizon Oil Rig killing 11 employees and spilling nearly 200 million gallons of oil before the resulting leak could be stopped. Wildlife, ecosystems, and people's livelihood were adversely affected. A lot of money and huge amounts of energy were expended on immediate clean-up efforts. The long-term impacts are still not known. The National Commission on the Deepwater Horizon Oil Spill and Offshore Drilling was set up to study what went wrong.

The Global Dependence of Transportation on Oil

Two-thirds of oil consumption is devoted to transportation, providing fuel for cars, trucks, trains and airplanes. For the United States and most developed societies, transportation is woven into the fabric of our lives, a necessity as central to daily operations as food or shelter. The concentration of oil reserves in a few regions or the world makes much of the world dependent on imported

energy for transportation. The rise in the price of oil in the last decade makes dependence on imported energy for transportation an economic as well as an energy issue. The United States, for example, now spends upwards of $350 billion annually on imported oil, a drain of economic resources that could be used to stimulate growth, create jobs, build infrastructure and promote social advances at home.

Coal

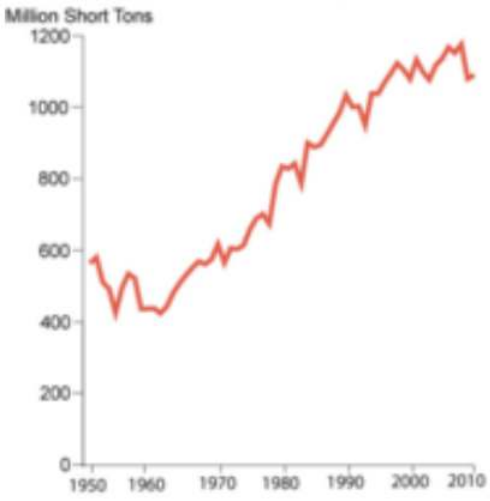


Figure $Page 6.2.1$. Historic U.S. Coal Production Graph shows U.S. Coal Production from 1950-2010. Source: U.S. Energy Information Administration

Unlike oil, **coal** is a solid. Due to its relatively low cost and abundance, coal is used to generate about half of the electricity consumed in the United States. Coal is the largest domestically produced source of energy. Coal production has doubled in the United States over the last sixty year (Figure $Page 6.2.1$). Current world reserves are estimated at 826,000 million tonnes, with nearly 30% of that in the United States. It is a major fuel resource that the United States controls domestically.

Coal is plentiful and inexpensive, when looking only at the market cost relative to the cost of other sources of electricity, but its extraction, transportation, and use produces a multitude of environmental impacts that the market cost does not truly represent. Coal emits sulfur dioxide, nitrogen oxide, and mercury, which have been linked to acid rain, smog, and health issues. Burning of coal emits higher amounts of carbon dioxide per unit of energy than the use of oil or natural gas. Coal accounted for 35% of the total United States emissions of carbon dioxide released into the Earth's atmosphere in 2010. Ash generated from combustion contributes to water contamination. Some coal mining has a negative impact on ecosystems and water quality, and alters landscapes and scenic views (such as with mountaintop mining).

There are also significant health effects and risks to coal miners and those living in the vicinity of coal mines. Traditional underground mining is risky to mine workers due to the risk of entrapment or death. Over the last 15 years, the U.S. Mine Safety and Health Administration has published the number of mine worker fatalities and it has varied from 18-48 per year. Twenty-nine miners died on April 6, 2010 in an explosion at the Upper Big Branch coal mine in West Virginia, contributing to the uptick in deaths between 2009 and 2010. In other countries, with less safety regulations, accidents occur more frequently. In May 2011, for example, three people died and 11 were trapped in a coalmine in Mexico for several days. There is also risk of getting **black lung disease** (pneumoconiosis). This is a disease of the lungs caused by the inhalation of coal dust over a long period of time**.** It causes coughing and shortness of breath. If exposure is stopped the outcome is good. However, the complicated form may cause shortness of breath that gets increasingly worse.

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Figure $Page 6.2.2$. Mountaintop Removal Coal Mining in Martin County, Kentucky Photograph shows mountaintop coal removal mining in Martin County, Kentucky. Source: Flashdark.

Mountaintop mining (MTM), while less hazardous to workers, has particularly detrimental effects on land resources. MTM is a surface mining practice involving the removal of mountaintops to expose coal seams, and disposing of the associated mining waste in adjacent valleys. This form of mining is very damaging to the environment because it literally removes the tops of mountains, destroying the existing habitat. Additionally, the debris from MTM is dumped into valleys burying streams and other important habitat.

Natural Gas

Natural gas meets 20% of world energy needs and 25% of United States needs. **Natural gas** is mainly composed of methane (CH_4) and is a very potent greenhouse gas. There are two types of natural gas. **Biogenic gas** is found at shallow depths and arises from anaerobic decay of organic matter by bacteria, like landfill gas. **Thermogenic gas** comes from the compression of organic matter and deep heat underground. They are found with petroleum in reservoir rocks and with coal deposits, and these fossil fuels are extracted together.

Natural gas is released into the atmosphere from coal mines, oil and gas wells, and natural gas storage tanks, pipelines, and processing plants. These leaks are the source of about 25% of total U.S. methane emissions, which translates to three percent of total U.S. greenhouse gas emissions. When natural gas is produced but cannot be captured and transported economically, it is "flared," or burned at well sites, which converts it to CO_2. This is considered to be safer and better than releasing methane into the atmosphere because CO_2 is a less potent greenhouse gas than methane.

In the last few years a new reserve of natural gas has been identified: shale resources. The United States possesses 2,552 trillion cubic feet (Tcf) (72.27 trillion cubic meters) of potential natural gas resources, with shale resources accounting for 827 Tcf (23.42 tcm). As natural gas prices increased it has become more economical to extract the gas from shale. Figure $Page 6.2.3$ shows the past and forecasted U.S. natural gas production and the various sources. The current reserves are enough to last about 110 years at the 2009 rate of U.S. consumption (about 22.8 Tcf per year -645.7 bcm per year).

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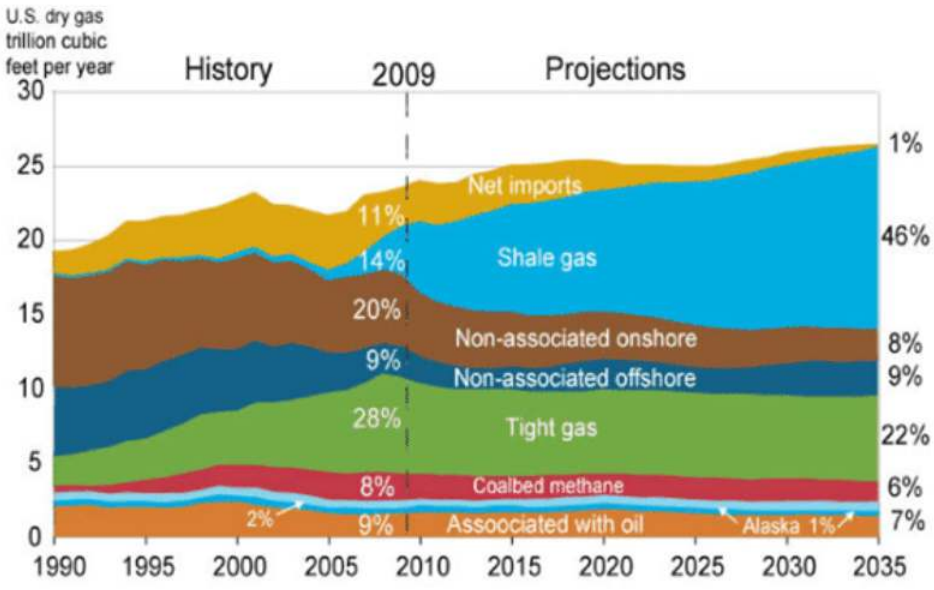


Figure $Page$6.2.3. U.S. Natural Gas Supply, 1990-2035 Graph shows U.S. historic and projected natural gas production from various sources. Source: U.S. Energy Information Administration

Natural gas is a preferred fossil fuel when considering its environmental impacts. Specifically, when burned, much less carbon dioxide (CO_2), nitrogen oxides, and sulfur dioxide are omitted than from the combustion of coal or oil. It also does not produce ash or toxic emissions.

Natural gas production can result in the production of large volumes of contaminated water. This water has to be properly handled, stored, and treated so that it does not pollute land and water supplies. Extraction of shale gas is more problematic than traditional sources due to a process nicknamed **fracking,** or fracturing of wells, since it requires large amounts of water (Figure $Page$6.2.4). The technique uses high-pressure fluids to fracture the normally hard shale deposits and release gas and oil trapped inside the rock. To promote the flow of gas out of the rock, small particles of solids are included in the fracturing liquids to lodge in the shale cracks and keep them open after the liquids are depressurized. The considerable use of water may affect the availability of water for other uses in some regions and this can affect aquatic habitats. If mismanaged, hydraulic fracturing fluid can be released by spills, leaks, or various other exposure pathways. The fluid contains potentially hazardous chemicals such as hydrochloric acid, glutaraldehyde, petroleum distillate, and ethylene glycol. The risks of fracking have been highlighted in popular culture in the documentary, Gasland (2010).

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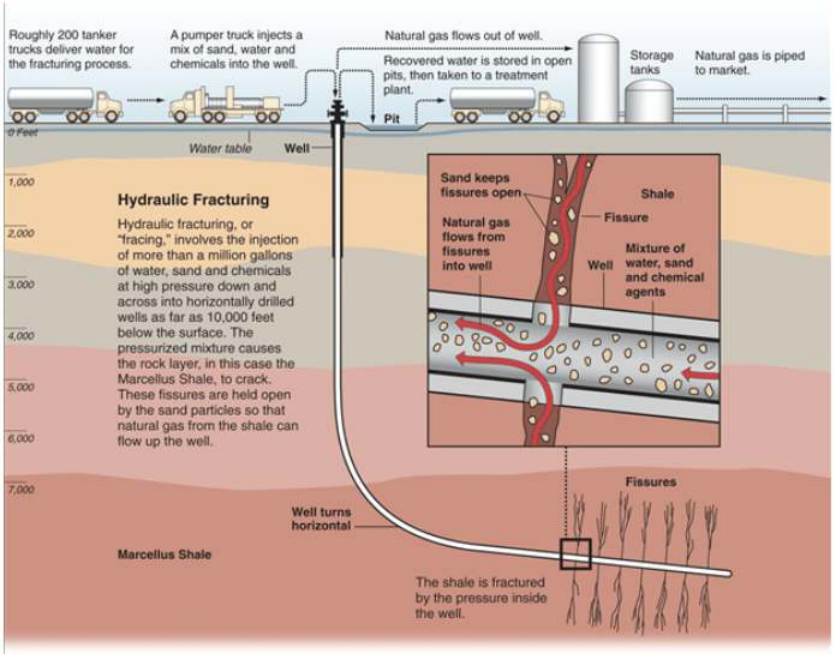


Figure $Page 6.2.4$. Graphic illustrates the process of hydraulic fracturing. Source: Al Granberg, ProPublica.

The raw gas from a well may contain many other compounds besides the methane that is being sought, including hydrogen sulfide, a very toxic gas. Natural gas with high concentrations of hydrogen sulfide is usually flared which produces CO_2, carbon monoxide, sulfur dioxide, nitrogen oxides, and many other compounds. Natural gas wells and pipelines often have engines to run equipment and compressors, which produce additional air pollutants and noise.

Contributions of Coal and Natural Gas to Electricity Generation

At present the fossil fuels used for electricity generation in the US are predominantly coal (44%) and natural gas (23%); petroleum accounts for approximately 1%. Coal electricity traces its origins to the early 20th Century, when it was the natural fuel for steam engines given its abundance, high energy density and low cost. gatural Gas is a later addition to the fossil electricity mix, arriving in significant quantities after World War II and with its greatest growth since 1990. Of the two fuels, coal emits almost twice the carbon dioxide as natural gas for the same heat output, making it significantly greater contributor to global warming and climate change.

The Future of Natural Gas and Coal

The future development of coal and natural gas depend on the degree of public and regulatory concern for carbon emissions, and the relative price and supply of the two fuels. Supplies of coal are abundant in the United States, and the transportation chain from mines to power plants is well established. The primary unknown factor is the degree of public and regulatory pressure that will be placed on carbon emissions. Strong regulatory pressure on carbon emissions would favor retirement of coal and addition of natural gas power plants. This trend is reinforced by the recent dramatic expansion of shale gas reserves in the United States due to advances in drilling technology. Shale natural gas production has increased 48% annually in the years 2006 – 2010, with more increases expected. Greater United States production of shale gas will gradually reduce imports and could eventually make the United States a net exporter of natural gas.

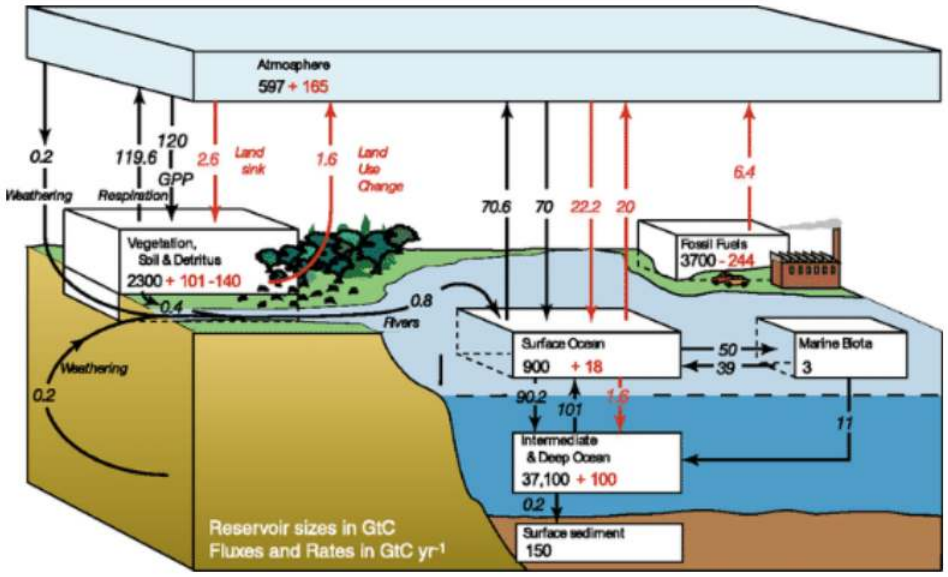


Figure $Page 6.2.5$. Global Carbon Cycle, 1990s The global carbon cycle for the 1990s, showing the main annual fluxes in GtC yr–1: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red. Source: Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, figure 7.3

Nuclear Power

Nuclear power is energy released from the radioactive decay of elements, such as uranium, which releases large amounts of energy. Nuclear power plants produce no carbon dioxide and, therefore, are often considered an **alternative fuel** (fuels other than fossil fuels)**.** Currently, world production of electricity from nuclear power is about 19.1 trillion KWh, with the United States producing and consuming about 22% of that. Nuclear power provides about 9% of the electricity in the United States (Figure $Page 6.2.7$).

There are environmental challenges with nuclear power. Mining and refining uranium ore and making reactor fuel demands a lot of energy. Also, nuclear power plants are very expensive and require large amounts of metal, concrete, and energy to build. The main environmental challenge for nuclear power is the wastes including uranium mill tailings, spent (used) reactor fuel, and other radioactive wastes. These materials have long radioactive half-lives and thus remain a threat to human health for thousands of years. The **half life** of a radioactive element is the time it takes for 50% of the material to radioactively decay. The U.S. Nuclear Regulatory Commission regulates the operation of nuclear power plants and the handling, transportation, storage, and disposal of radioactive materials to protect human health and the environment.

By volume**,** the waste produced from mining uranium, called **uranium mill tailings,** is the largest waste and contains the radioactive element radium, which decays to produce radon, a radioactive gas. **High-level radioactive waste** consists of used nuclear reactor fuel. This fuel is in a solid form consisting of small fuel pellets in long metal tubes and must be stored and handled with multiple containment, first cooled by water and later in special outdoor concrete or steel containers that are cooled by air. There is no long-term storage facility for this fuel in the United States.

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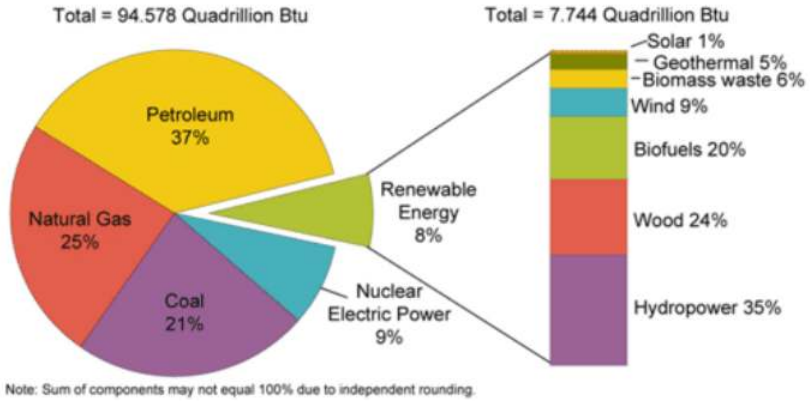


Figure $Page 6.2.7$. U.S. Energy Consumption by Energy Source, 2009 Renewable energy makes up 8% of U.S. energy consumption. Source: U.S. Energy Information Administration

There are many other regulatory precautions governing permitting, construction, operation, and decommissioning of nuclear power plants due to risks from an uncontrolled nuclear reaction. The potential for contamination of air, water and food is high should an uncontrolled reaction occur. Even when planning for worst-case scenarios, there are always risks of unexpected events. For example, the March 2011 earthquake and subsequent tsunami that hit Japan resulted in reactor meltdowns at the Fukushima Daiichi Nuclear Power Station, causing massive damage to the surrounding area.

Debating Nuclear Energy

From a sustainability perspective, nuclear electricity presents an interesting dilemma. On the one hand, nuclear electricity produces no carbon emissions, a major sustainable advantage in a world facing anthropogenic climate change. On the other hand, nuclear electricity produces dangerous waste that i) must be stored out of the environment for thousands of years, ii) can produce bomb-grade plutonium and uranium that could be diverted by terrorists or others to destroy cities and poison the environment, and iii) threatens the natural and built environment through accidental leaks of long-lived radiation. Thoughtful scientists, policy makers, and citizens must weigh the benefit of this source of carbon-free electricity against the environmental risk of storing spent fuel, the societal risk of nuclear proliferation, and the impact of accidental or deliberate release of radiation. There are very few examples of humans having the power to permanently change the dynamics of the earth. Global climate change from carbon emissions is one example, and radiation from the explosion of a sufficient number of nuclear weapons is another. Nuclear electricity touches both of these opportunities, on the positive side for reducing carbon emissions and on the negative side for the risk of nuclear proliferation.

Nuclear electricity came on the energy scene remarkably quickly. Following the development of nuclear technology at the end of World War II for military ends, nuclear energy quickly acquired a new peacetime path for inexpensive production of electricity. Eleven years after the end of World War II, a very short time in energy terms, the first commercial nuclear reactor produced electricity at Calder Hall in Sellafield, England. The number of nuclear reactors grew steadily to more than 400 by 1990, four years after the Chernobyl disaster in 1986 and eleven years following Three Mile Island in 1979. Since 1990, the number of operating reactors has remained approximately flat, with new construction balancing decommissioning due to public and government reluctance to proceed with nuclear electricity expansion plans.

The outcome of this debate will determine whether the world experiences a nuclear renaissance that has been in the making for several years. The global discussion has been strongly impacted by the unlikely nuclear accident in Fukushima, Japan in March 2011. The Fukushima nuclear disaster was caused by an earthquake and tsunami that disabled the cooling system for a nuclear energy complex consisting of operating nuclear reactors and storage pools for underwater storage of spent nuclear fuel ultimately causing a partial meltdown of some of the reactor cores and release of significant radiation. This event, 25 years after Chernobyl, reminds us that safety and public confidence are especially important in nuclear energy; without them expansion of nuclear energy will not happen.

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Page 6.3: Renewable Energy Sources

Hydropower

Hydropower (hydroelectric) relies on water to spin turbines and create electricity. It is considered a clean and renewable source of energy because it does not directly produce pollutants and because the source of power is regenerated. Hydropower provides 35% of the United States' renewable energy consumption.



Figure $Page 6.3.1$. Hoover Power Plant View of Hoover Power Plant on the Colorado River as seen from above. Source: U.S. Department of the Interior

Hydropower dams and the reservoirs they create can have environmental impacts. For example, migration of fish to their upstream spawning areas can be obstructed by dams. In areas where salmon must travel upstream to spawn, such as along the Columbia River in Washington and Oregon, the dams block their way. This problem can be partially alleviated by using "fish ladders" that help salmon get around the dams. Fish traveling downstream, however, can get killed or injured as water moves through turbines in the dam. Reservoirs and operation of dams can also affect aquatic habitats due to changes in water temperatures, water depth, chemistry, flow characteristics, and sediment loads, all of which can lead to significant changes in the ecology and physical characteristics of the river both upstream and downstream. As reservoirs fill with water it may cause natural areas, farms, cities, and archeological sites to be inundated and force populations to relocate.

Small hydropower systems

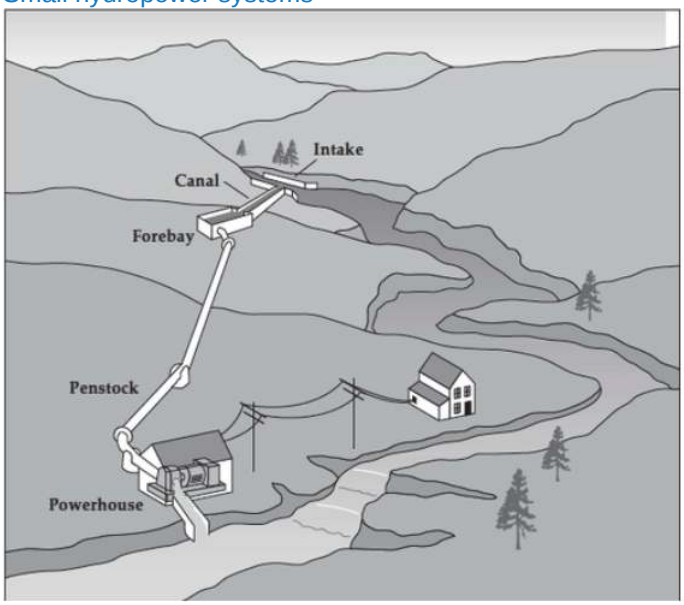


Figure $Page 6.3.2$. Microhydropower system. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage

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reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity.

Large-scale dam hydropower projects are often criticized for their impacts on wildlife habitat, fish migration, and water flow and quality. However, small **run-of- the-river projects** are free from many of the environmental problems associated with their large-scale relatives because they use the natural flow of the river, and thus produce relatively little change in the stream channel and flow. The dams built for some run-of-the-river projects are very small and impound little water, and many projects do not require a dam at all. Thus, effects such as oxygen depletion, increased temperature, decreased flow, and impeded upstream migration are not problems for many run-of-the-river projects.

Small hydropower projects offer emissions-free power solutions for many remote communities throughout the world, such as those in Nepal, India, China, and Peru, as well as for highly industrialized countries like the United States. **Small hydropower systems** are those that generate between .01 to 30 MW of electricity. Hydropower systems that generate up to 100 kilowatts (kW) of electricity are often called **micro hydropower** systems (Figure $Page6.3.2$). Most of the systems used by home and small business owners would qualify as microhydropower systems. In fact, a 10 kW system generally can provide enough power for a large home, a small resort, or a hobby farm.

Municipal Solid Waste

Municipal solid waste (MSW) is commonly known as garbage and can create electricity by burning it directly or by burning the methane produced as it decays. Waste to energy processes are gaining renewed interest as they can solve two problems at once: disposal of waste and production of energy from a renewable resource. Many of the environmental impacts are similar to those of a coal plant: air pollution, ash generation, etc. Because the fuel source is less standardized than coal and hazardous materials may be present in MSW, incinerators and waste-to-energy power plants need to clean the gases of harmful materials. The U.S. EPA regulates these plants very strictly and requires anti-pollution devices to be installed. Also, while incinerating at high temperature many of the toxic chemicals may break down into less harmful compounds. The ash from these plants may contain high concentrations of various metals that were present in the original waste. If ash is clean enough it can be "recycled" as an MSW landfill cover or to build roads, cement block and artificial reefs

Biofuel



Figure $Page6.3.3$. Woodchips Photograph shows a pile of woodchips, which are a type of biomass. Source: Ulrichulrich

Biomass refers to material made by organisms, such as cells and tissues. In terms of energy production, biomass is almost always derived from plants, and to a lesser extent, algae. For biomass to be a sustainable option, it usually needs to come from waste material, such as lumber mill sawdust, paper mill sludge, yard waste, or oat hulls from an oatmeal processing plant, material that would otherwise just rot. Livestock manure and human waste could also be considered biomass. The use of biomass can help mitigate climate change because when burned it adds no new carbon to the atmosphere. Thinking back to the carbon cycle (chapter 3), you will recall that photosynthesis removes CO_2 through the process of carbon fixation. When biomass is burnt, CO_2 is created,

but this is equal to the amount of CO_2captured during carbon fixation. Thus, biomass is a **carbon neutral** energy source because it doesn't add new CO_2 to the carbon cycle. Each type of biomass must be evaluated for its environmental and social impact in order to determine if it is really advancing sustainability and reducing environmental impacts. For example, cutting down large swaths of forests just for energy production is not a sustainable option because our energy demands are so great that we would quickly deforest the world, destroying critical habitat.

Burning Wood

Using wood, and charcoal made from wood, for heating and cooking can replace fossil fuels and may result in lower CO_2 emissions. If wood is harvested from forests or woodlots that have to be thinned or from urban trees that fall down or needed be cut down anyway, then using it for biomass does not impact those ecosystems. However, wood smoke contains harmful pollutants like carbon monoxide and particulate matter. For home heating, it is most efficient and least polluting when using a modern wood stove or fireplace insert that are designed to release small amounts of particulates. However, in places where wood and charcoal are major cooking and heating fuels such as in undeveloped countries, the wood may be harvested faster than trees can grow resulting in deforestation.

Biomass can be used in small power plants. For instance, Colgate College has had a wood-burning boiler since the mid-1980's and in one year it processed approximately 20,000 tons of locally and sustainably harvested wood chips, the equivalent of 1.17 million gallons (4.43 million liters) of fuel oil, avoiding 13,757 tons of emissions and saving the university over $1.8 million in heating costs. The University's steam-generating wood-burning facility now satisfies more than 75% of the campus's heat and domestic hot water needs.

Landfill Gas or Biogas

Landfill gas (**biogas**) is a sort of man-made "biogenic" gas as discussed above. Methane is formed as a result of biological processes in sewage treatment plants, waste landfills, anaerobic composting, and livestock manure management systems. This gas is captured and burned to produce heat or electricity. The electricity may replace electricity produced by burning fossil fuels and result in a net reduction in CO_2 emissions. The only environmental impacts are from the construction of the plant itself, similar to that of a natural gas plant.

Bioethanol and Biodiesel

Bioethanol and **biodiesel** are liquid biofuels manufactured from plants, typically crops. Bioethanol can be easily fermented from sugar cane juice, as is done in Brazil. Bioethanol can also be fermented from broken down corn starch, as is mainly done in the United States. The economic and social effects of growing plants for fuels need to be considered, since the land, fertilizers, and energy used to grow biofuel crops could be used to grow food crops instead. The competition of land for fuel vs. food can increase the price of food, which has a negative effect on society. It could also decrease the food supply increasing malnutrition and starvation globally. Also, in some parts of the world, large areas of natural vegetation and forests have been cut down to grow sugar cane for bioethanol and soybeans and palm-oil trees to make biodiesel. This is not sustainable land use. Biofuels may be derived from parts of plants not used for food, such as stalks, thus reducing that impact. Biodiesel can be made from used vegetable oil and has been produced on a very local basis. Compared to petroleum diesel, biodiesel combustion produces less sulfur oxides, particulate matter, carbon monoxide, and unburned and other hydrocarbons, but it produces more nitrogen oxide.

Liquid biofuels typically replace petroleum and are used to power vehicles. Although ethanol-gasoline mixtures burn cleaner than pure gasoline, they also are more volatile and thus have higher "evaporative emissions" from fuel tanks and dispensing equipment. These emissions contribute to the formation of harmful, ground level ozone and smog. Gasoline requires extra processing to reduce evaporative emissions before it is blended with ethanol.

Geothermal Energy

Five percent of the United States' renewable energy comes from **geothermal energy:** using the heat of Earth's subsurface to provide endless energy. Geothermal systems utilize a heat-exchange system that runs in the subsurface about 20 feet (5 meters) below the surface where the ground is at a constant temperature. The system uses the earth as a heat source (in the winter) or a heat sink (in the summer). This reduces the energy consumption required to generate heat from gas, steam, hot water, and conventional

electric air-conditioning systems.The environmental impact of geothermal energy depends on how it is being used. Direct use and heating applications have almost no negative impact on the environment.

Geothermal power plants do not burn fuel to generate electricity so their emission levels are very low. They release less than 1% of the carbon dioxide emissions of a fossil fuel plant. Geothermal plants use scrubber systems to clean the air of hydrogen sulfide that is naturally found in the steam and hot water. They emit 97% less acid rain-causing sulfur compounds than are emitted by fossil fuel plants. After the steam and water from a geothermal reservoir have been used, they are injected back into the earth.

Solar Energy



Figure *Page*6.3.4. Rooftop Solar Installations Rooftop solar installation on Douglas Hall at the University of Illinois at Chicago has no effect on land resources, while producing electricity with zero emissions. Source: Office of Sustainability, UIC

Solar power converts the energy of light into electrical energy and has minimal impact on the environment, depending on where it is placed. In 2009, 1% of the renewable energy generated in the United States was from solar power (1646 MW) out of the 8% of the total electricity generation that was from renewable sources. The manufacturing of **photovoltaic** (PV) cells generates some hazardous waste from the chemicals and solvents used in processing. Often solar arrays are placed on roofs of buildings or over parking lots or integrated into construction in other ways. However, large systems may be placed on land and particularly in deserts where those fragile ecosystems could be damaged if care is not taken. Some solar thermal systems use potentially hazardous fluids (to transfer heat) that require proper handling and disposal. Concentrated solar systems may need to be cleaned regularly with water, which is also needed for cooling the turbine-generator. Using water from underground wells may affect the ecosystem in some arid locations.

Wind

Wind energy is a renewable energy source that is clean and has very few environmental challenges. Wind turbines are becoming a more prominent sight across the United States, even in regions that are considered to have less wind potential. Wind turbines (often called windmills) do not release emissions that pollute the air or water (with rare exceptions), and they do not require water for cooling. The U.S. wind industry had 40,181 MW of wind power capacity installed at the end of 2010, with 5,116 MW installed in 2010 alone, providing more than 20% of installed wind power around the globe. According to the American Wind Energy Association, over 35% of all new electrical generating capacity in the United States since 2006 was due to wind, surpassed only by natural gas.


Figure $Page 6.3.5$. Twin Groves Wind Farm, Illinois Wind power is becoming a more popular source of energy in the United States. Source: Office of Sustainability, UIC

Because a wind turbine has a small physical footprint relative to the amount of electricity it produces, many wind farms are located on crop and pasture land. They contribute to economic sustainability by providing extra income to farmers and ranchers, allowing them to stay in business and keep their property from being developed for other uses. For example, energy can be produced by installing wind turbines in the Appalachian mountains of the United States instead of engaging in mountain top removal for coal mining. Offshore wind turbines on lakes or the ocean may have smaller environmental impacts than turbines on land.

Wind turbines do have a few environmental challenges. There are aesthetic concerns to some people when they see them on the landscape. A few wind turbines have caught on fire, and some have leaked lubricating fluids, though this is relatively rare. Some people do not like the sound that wind turbine blades make. Turbines have been found to cause bird and bat deaths particularly if they are located along their migratory path. This is of particular concern if these are threatened or endangered species. There are ways to mitigate that impact and it is currently being researched. There are some small impacts from the construction of wind projects or farms, such as the construction of service roads, the production of the turbines themselves, and the concrete for the foundations. However, overall analysis has found that turbines make much more energy than the amount used to make and install them.

Interest in Renewable Energy

Strong interest in renewable energy in the modern era arose in response to the oil shocks of the 1970s, when the Organization of Petroleum Exporting Countries (OPEC) imposed oil embargos and raised prices in pursuit of geopolitical objectives. The shortages of oil, especially gasoline for transportation, and the eventual rise in the price of oil by a factor of approximately 10 from 1973 to 1981 disrupted the social and economic operation of many developed countries and emphasized their precarious dependence on foreign energy supplies. The reaction in the United States was a shift away from oil and gas to plentiful domestic coal for electricity production and the imposition of fuel economy standards for vehicles to reduce consumption of oil for transportation. Other developed countries without large fossil reserves, such as France and Japan, chose to emphasize nuclear (France to the 80% level and Japan to 30%) or to develop domestic renewable resources such as hydropower and wind (Scandinavia), geothermal (Iceland), solar, biomass and for electricity and heat. As oil prices collapsed in the late 1980s interest in renewables, such as wind and solar that faced significant technical and cost barriers, declined in many countries, while other renewables, such as hydropower and biomass, continued to experience growth.

The increasing price and volatility of oil prices since 1998, and the increasing dependence of many developed countries on foreign oil (60% of United States and 97% of Japanese oil was imported in 2008) spurred renewed interest in renewable alternatives to ensure energy security. A new concern, not known in previous oil crises, added further motivation: our knowledge of the emission of greenhouse gases and their growing contribution to climate change. An additional economic motivation, the high cost of foreign oil payments to supplier countries (approximately $350 billion/year for the United States at 2011 prices), grew increasingly important as developed countries struggled to recover from the economic recession of 2008. These energy security, carbon emission, and climate change concerns drive significant increases in fuel economy standards, fuel switching of transportation from uncertain and volatile foreign oil to domestic electricity and biofuels, and production of electricity from low carbon sources.

Physical Origin of Renewable Energy

Although renewable energy is often classified as hydro, solar, wind, biomass, geothermal, wave and tide, all forms of renewable energy arise from only three sources: the light of the sun, the heat of the earth's crust, and the gravitational attraction of the moon and sun. Sunlight provides by far the largest contribution to renewable energy. The sun provides the heat that drives the weather, including the formation of high- and low-pressure areas in the atmosphere that make wind. The sun also generates the heat required for vaporization of ocean water that ultimately falls over land creating rivers that drive hydropower, and the sun is the energy source for photosynthesis, which creates biomass. Solar energy can be directly captured for water and space heating, for driving conventional turbines that generate electricity, and as excitation energy for electrons in semiconductors that drive photovoltaics. The sun is also responsible for the energy of fossil fuels, created from the organic remains of plants and sea organisms compressed and heated in the absence of oxygen in the earth's crust for tens to hundreds of millions of years. The time scale for fossil fuel regeneration, however, is too long to consider them renewable in human terms.

Geothermal energy originates from heat rising to the surface from earth's molten iron core created during the formation and compression of the early earth as well as from heat produced continuously by radioactive decay of uranium, thorium and potassium in the earth's crust. Tidal energy arises from the gravitational attraction of the moon and the more distant sun on the earth's oceans, combined with rotation of the earth. These three sources – sunlight, the heat trapped in earth's core and continuously generated in its crust, and gravitational force of the moon and sun on the oceans – account for all renewable energy.

Capacity and Geographical Distribution

Although renewable energies such as wind and solar have experienced strong growth in recent years, they still make up a small fraction of the world's total energy needs. The largest share comes from traditional biomass, mostly fuel wood gathered in traditional societies for household cooking and heating, often without regard for sustainable replacement. Hydropower is the next largest contributor, an established technology that experienced significant growth in the 20th Century. The other contributors are more recent and smaller in contribution: water and space heating by biomass combustion or harvesting solar and geothermal heat, biofuels derived from corn or sugar cane, and electricity generated from wind, solar and geothermal energy. Wind and solar electricity, despite their large capacity and significant recent growth, still contributed less than 1% of total energy in 2008.

The potential of renewable energy resources varies dramatically. Solar energy is by far the most plentiful, delivered to the surface of the earth at a rate of 120,000 Terawatts (TW), compared to the global human use of 15 TW. To put this in perspective, covering 100×100 km2 of desert with 10% efficient solar cells would produce 0.29 TW of power, about 12% of the global human demand for electricity. To supply all of the earth's electricity needs (2.4 TW in 2007) would require 7.5 such squares, an area about the size of Panama (0.05% of the earth's total land area). The world's conventional oil reserves are estimated at three trillion barrels, including all the oil that has already been recovered and that remain for future recovery. The solar energy equivalent of these oil reserves is delivered to the earth by the sun in 1.5 days.

The geographical distribution of useable renewable energy is quite uneven. Sunlight, often thought to be relatively evenly distributed, is concentrated in deserts where cloud cover is rare. Winds are up to 50% stronger and steadier offshore than on land. Hydroelectric potential is concentrated in mountainous regions with high rainfall and snowmelt. Biomass requires available land that does not compete with food production, and adequate sun and rain to support growth.

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Page 6.4: Chapter Resources

Summary

We derive our energy from a multitude of resources that have varying environmental challenges related to air and water pollution, land use, carbon dioxide emissions, resource extraction and supply, as well as related safety and health issues. Each resource needs to be evaluated within the sustainability paradigm. Coal (45 percent) and gas (23 percent) are the two primary fossil fuels for electricity production in the United States. Coal combustion produces nearly twice the carbon emissions of gas combustion. Increasing public opinion and regulatory pressure to lower carbon emissions are shifting electricity generation toward gas and away from coal. Oil for transportation and electricity generation are the two biggest users of primary energy and producers of carbon emissions in the United States. Transportation is almost completely dependent on oil and internal combustion engines for its energy. The concentration of oil in a few regions of the world creates a transportation energy security issue. Nuclear electricity offers the sustainable benefit of low carbon electricity at the cost of storing spent fuel out of the environment for up to hundreds of thousands of years. Reprocessing spent fuel offers the advantages of higher energy efficiency and reduced spent fuel storage requirements with the disadvantage of higher risk of weapons proliferation through diversion of the reprocessed fuel stream.

Strong interest in renewable energy arose in the 1970s as a response to the shortage and high price of imported oil, which disrupted the orderly operation of the economies and societies of many developed countries. Today there are new motivations, including the realization that growing greenhouse gas emission accelerates global warming and threatens climate change, the growing dependence of many countries on foreign oil, and the economic drain of foreign oil payments that slow economic growth and job creation. There are three ultimate sources of all renewable and fossil energies: sunlight, the heat in the earth's core and crust, and the gravitational pull of the moon and sun on the oceans. Renewable energies are relatively recently developed and typically operate at lower efficiencies than mature fossil technologies. Like early fossil technologies, however, renewables can be expected to improve their efficiency and lower their cost over time, promoting their economic competitiveness and widespread deployment. The future deployment of renewable energies depends on many factors, including the availability of suitable land, the technological cost of conversion to electricity or other uses, the costs of competing energy technologies, and the future need for energy.

Review Questions

1. Which one of the following is not a renewable source of energy?

   A. Nuclear
   B. Wind
   C. Solar
   D. Hydropower
   E. Geothermal

2. Coal, oil, and natural gas are created _____ and contain the remains of_____.

   A. over millions of years; algae and plants
   B. over millions of years; dinosaurs and other animals
   C. over hundreds of years; algae and plants
   D. over hundreds of years; dinosaurs and other animals
   E. instantaneously; comet fragments

3. Which one of the following is a consortium of oil-producing countries that hold a significant portion of the world's oil reserves (and thus influence global oil prices)?

   A. UAE
   B. OPEC
   C. UN
   D. CITES
   E. UNESCO

4. About 44% of the electricity in the US is produced from _____. It produces about twice as much CO_2 as an equivalent amount of _____.

   A. Burning natural gas; coal

B. Hydropower; solar
C. Natural gas; Geothermal
D. Hydropower; geothermal
E. Burning coal; natural gas

5. Which one of the following is not true regarding nuclear power?

A. Energy is captured from the radioactive decay of elements
B. Nuclear power is considered an alternative fuel
C. Radioactive wastes must be stored 2-5 years before disposal
D. No CO2 is directly produced in nuclear power plants
E. Nuclear power is used to produce electricity

6. Which one of the following directly produces CO_2 but is considered carbon neutral?

A. Wind
B. Biodiesel
C. Oil
D. Coal
E. Hydropower

7. The original source of energy that powers both wind energy and hydropower is…

A. Precipitation
B. Rotation of the Earth
C. The sun
D. Gravity
E. Radioactive decay within the Earth's mantle

8. Burning sawdust that is leftover from lumber production and using it to generate electricity would be an example of which one of the following?

A. Municipal solid waste
B. Biofuel
C. Biogas
D. Bioethanol
E. Biofission

9. In the process of fracking, how is gas and oil extracted?

A. Layers of earth are stripped away from the surface, exposing the fossil fuels
B. Mining tunnels are created and the fossil fuels are extracted by teams working below ground
C. Ocean sediments are mined and the fossil fuels are chemically extracted
D. High-pressure fluids are injected underground to force out the fossil fuels
E. Offshore drilling pads tap into pre-existing cracks in the Earth's crust

10. What fundamental similarity is shared between the following energy sources: biogas and municipal solid waste?

A. Both burn waste to generate CO2, which itself is burned to create electricity
B. Both chemically transform waste into oil
C. Both trap the heat generated from decaying waste and use it to generate energy
D. Both rely on the generation and combustion of methane
E. Both produce no CO_2

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

7: Conservation and Biodiversity

Learning Outcomes

- Describe biodiversity
- Explain how species evolve through natural selection
- Identify benefits of biodiversity to humans
- Explain the effects of habitat loss, exotic species, and hunting on biodiversity
- Identify the early and predicted effects of climate change on biodiversity
- Explain the legislative framework for conservation
- Identify examples of the effects of habitat restoration

Page 7.1: Introduction to Biodiversity

Page 7.2: Origin of Biodiversity

Page 7.3: Importance of Biodiversity

Page 7.4: Threats to Biodiversity

Page 7.5: Preserving Biodiversity

Page 7.6: Chapter Resources

Thumbnail image - Habitat destruction through deforestation, especially of tropical rainforests as seen in this satellite view of Amazon rainforests in Brazil, is a major cause of the current decline in biodiversity. (credit: modification of work by Jesse Allen and Robert Simmon, NASA Earth Observatory)

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Page 7.1: Introduction to Biodiversity

Earth is home to an impressive array of life forms. From single-celled organisms to creatures made of many trillions of cells, life has taken on many wonderful shapes and evolved countless strategies for survival. Recall that cell theory dictates that all living things are made of one or more cells. Some organisms are made of just a single cell, and are thus referred to as **unicellular**. Organisms containing more than one cell are said to be **multicellular.** Despite the wide range of organisms, there exists only two fundamental cell plans: prokaryotic and eukaryotic. The main difference these two cell plans is that eukaryotic cells have internal, membrane-bound structures called organelles (see chp 2.3). Thus, if you were to microscopically analyze the cells of any organism on Earth, you would find either prokaryotic or eukaryotic cells depending on the type of organism.

Biologists name, group, and classify organisms based on similarities in genetics and morphology. This branch of biological science is known as **taxonomy**. Taxonomists group organisms into categories that range from very broad to very specific (Figure $Page7.1.1$). The broadest category is called **domain** and the most specific is **species** (notice the similarities between the words *specific* and *species*). Currently, taxonomists recognize three domains: Bacteria, Archaea, and Eukarya. All life forms are classified within these three domains.

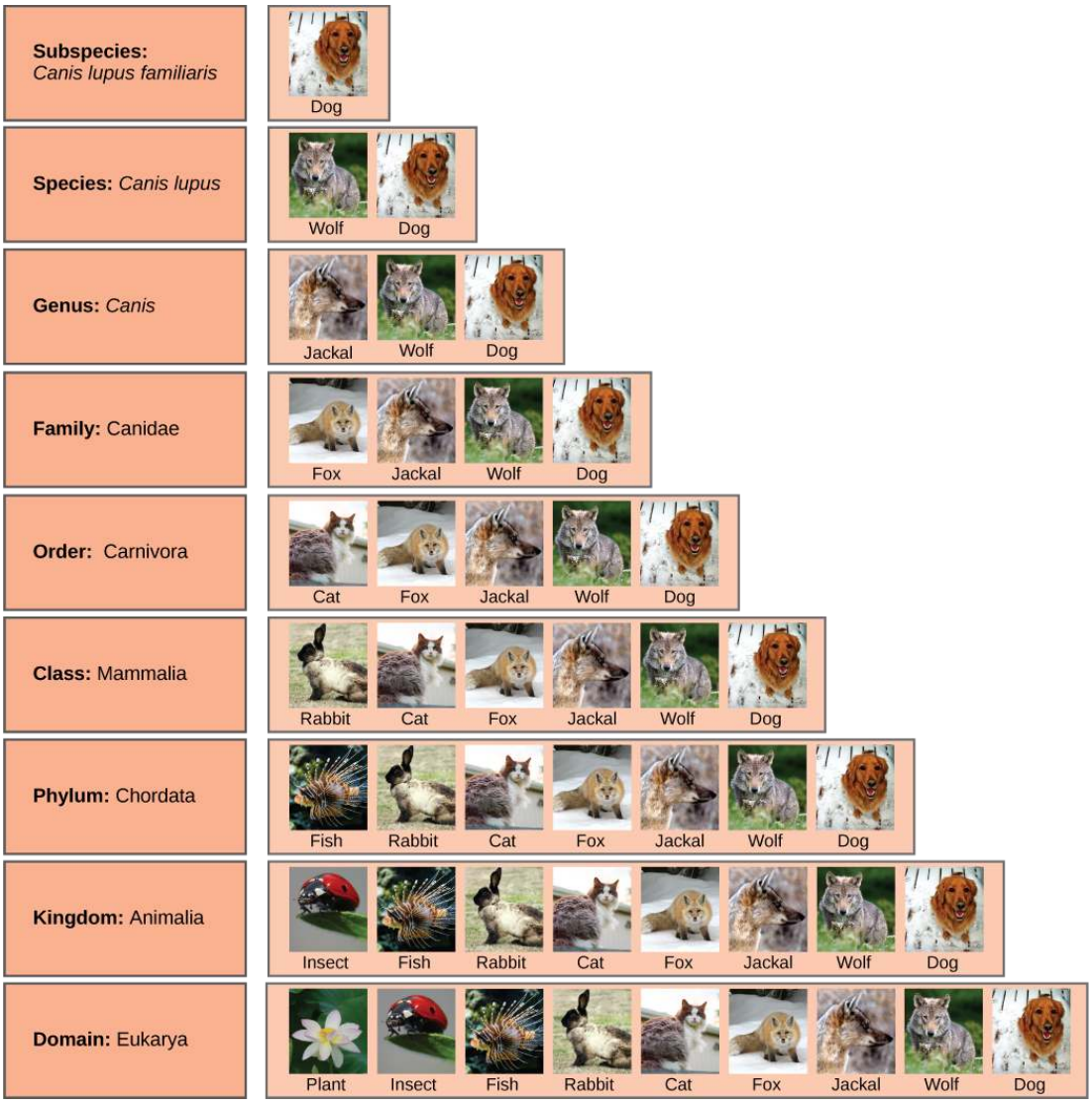


Figure $Page7.1.1$. This illustration shows the taxonomic groups, in sequence, with examples. *This illustration by OpenStax is licensed under CC BY 4.0*

Domain Bacteria

Domain Bacteria includes prokaryotic, unicellular organisms (Figure $Page 7.1.2$). They are incredibly abundant and found in nearly every imaginable type of habitat, including your body. While many people view bacteria only as disease-causing organisms, most species are actually either benign or beneficial to humans. While it is true that some bacteria may cause disease in people, this is more the exception than the rule.

Bacteria are well-known for their metabolic diversity. **Metabolism** is a general term describing the complex biochemistry that occurs inside of cells. Many species of bacteria are **autotrophs**, meaning they can create their own food source without having to eat other organisms. Most autotrophic bacteria do this by using photosynthesis, a process that converts light energy into chemical energy that can be utilized by cells. A well-known and ecologically-important group of photosynthetic bacteria is **cyanobacteria**. These are sometimes referred to a blue-green algae, but this name is not appropriate because, as you will see shortly, algae are organisms that belong to domain Eukarya. Cyanobacteria play important roles in food webs of aquatic systems, such as lakes.

Other species of bacteria are **heterotrophs**, meaning that they need to acquire their food by eating other organisms. This classification includes the bacteria that cause disease in humans (*during an infection, the bacteria is eating you*). However, most heterotrophic bacteria are harmless to humans. In fact, you have hundreds of species of bacteria living on your skin and in your large intestine that do you no harm. Beyond your body, heterotrophic bacteria play vital roles in ecosystems, especially soil-dwelling bacteria that decompose living matter and make nutrients available to plants.

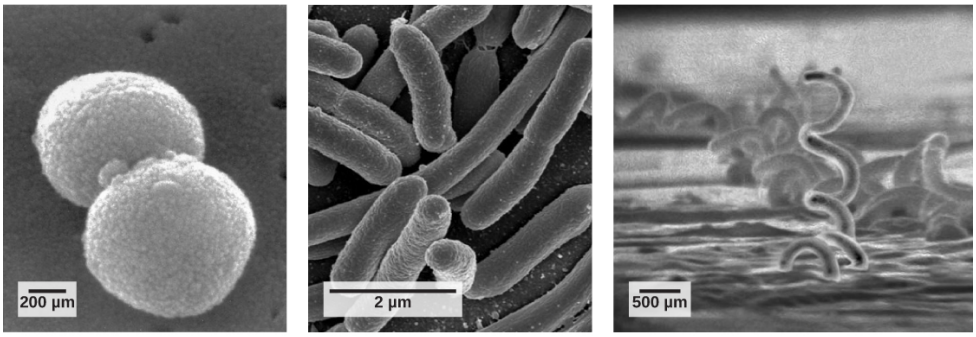


Figure $Page 7.1.2$. Many prokaryotes fall into three basic categories based on their shape: (a) cocci, or spherical; (b) bacilli, or rod-shaped; and (c) spirilla, or spiral-shaped. (credit a: modification of work by Janice Haney Carr, Dr. Richard Facklam, CDC; credit c: modification of work by Dr. David Cox, CDC; scale-bar data from Matt Russell). *This figure by OpenStax is licensed under CC BY 4.0*

Domain Archaea

Like bacteria, organisms in **domain Archaea** are prokaryotic and unicellular. Superficially, they look a lot like bacteria, and many biologists confused them as bacteria until a few decades ago. But hiding in their genes is a story that modern DNA analysis has recently revealed: archaeans are so different genetically that they belong in their own domain.

Many archaean species are found in some of the most inhospitable environments, areas of immense pressure (bottom of the ocean), salinity (such as the Great Salt Lake), or heat (geothermal springs). Organisms that can tolerate and even thrive in such conditions are known as **extremophiles**. (*It should be noted that many bacteria are also extremophiles*). Along with genetic evidence, the fact that a large percentage of archaeans are extremophiles suggests that they may be descendants of some of the most ancient lifeforms on Earth; life that originated on a young planet that was inhospitable by today's standards.

For whatever reason, archaeans are not as abundant in and on the human body as bacteria, and they cause substantially fewer diseases. Research on archaeans continues to shed light on this interesting and somewhat mysterious domain.

Domain Eukarya

This domain is most familiar to use because it includes humans and other animals, along with plants, fungi, and a lesser-known group, the protists. Unlike the other domains, **Domain Eukarya**contains multicellular organisms, in addition to unicellular species. The domain is characterized by the presence of eukaryotic cells. For this domain, you will be introduced to several of its kingdoms. **Kingdom** is the taxonomic grouping immediately below domain (see Figure $Page 7.1.1$).

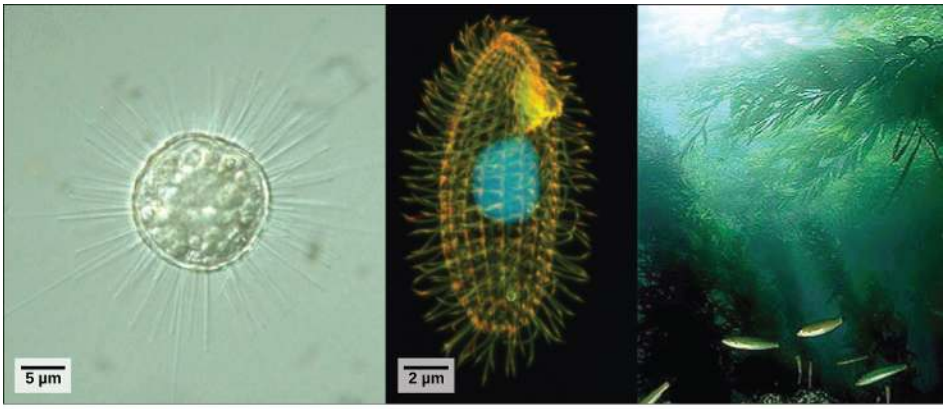
Kingdom Animalia is comprised of multicellular, heterotrophic organisms. This kingdom includes humans and other primates, insects, fish, reptiles, and many other types of animals. **Kingdom Plantae** includes multicellular, autotrophic organisms. Except for a few species that are parasites, plants use photosynthesis to meet their energy demands.



(a) (b) (c) Figure *Page*7.1.3. The (a) familiar mushroom is only one type of fungus. The brightly colored fruiting bodies of this (b) coral fungus are displayed. This (c) electron micrograph shows the spore-bearing structures of Aspergillus, a type of toxic fungi found mostly in soil and plants. (credit a: modification of work by Chris Wee; credit b: modification of work by Cory Zanker; credit c: modification of work by Janice Haney Carr, Robert Simmons, CDC; scale-bar data from Matt Russell). *This work by OpenStax is licensed under CC BY 4.0.*

Kingdom Fungi includes multicellular and unicellular, heterotrophic fungi. Fungi are commonly mistaken for plants because some species of fungi grow in the ground. Fungi are fundamentally different from plants in that they do not perform photosynthesis and instead feed on the living matter of others. Another misconception is that all fungi are mushrooms. A mushroom is a temporary reproductive structure used by some fungal species, but not all. Some fungi take the form of molds and mildews, which are commonly seen on rotting food. Lastly, **yeast** are unicellular fungi. Many species of yeast are important to humans, especially baker's and brewer's yeast. Through their metabolism, these yeast produce CO2 gas and alcohol. The former makes bread rise and the latter is the source for all alcoholic beverages.

Protists refer to a highly disparate group that was formerly its own kingdom until recent genetic analysis indicated that it should be split in to many kingdoms (Figure *Page*7.1.4). As a group, protists are very diverse and include unicellular, multicellular, heterotrophic, and autotrophic organisms. The term 'protist' was used as a catchall for any eukaryote that was neither animal, plant, or fungus. Examples of protists include macroalgae such as kelps and seaweeds, microalgae such as diatoms and dinoflagellates, and important disease-causing microbes such as *Plasmodium*, the parasite that causes malaria. Sadly, malaria kills hundreds of thousands of people every year.



(a) (b) (c) Figure *Page*7.1.4. Protists range from the microscopic, single-celled (a) *Acanthocystis turfacea and the (b) ciliate Tetrahymena thermophilato the enormous, multicellular (c) kelps (Chromalveolata) that extend for hundreds of feet in underwater "forests." (credit a: modification of work by Yuiuji Tsukii; credit b: modification of work by Richard Robinson, Public Library of Science; credit c: modification of work by Kip Evans, NOAA; scale-bar data from Matt Russell). This work by OpenStax is licensed under CC BY 4.0*

With this cursory and fundamental understanding of biological diversity, you are now better equipped to study the role of biodiversity in the biosphere and in human economics, health, and culture. Each life form, even the smallest microbe, is a fascinating and and complex living machine. This complexity means we will likely never fully understand each organism and the myriad ways they interact with each other, with us, and with their environment. Thus, it is wise to value biodiversity and take measures to conserve it.

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Page 7.2: Origin of Biodiversity

What biological process is responsible for biodiversity?

All species —from the bacteria on our skin to the birds outside—evolved at some point from a different species. Although it may seem that living things today stay much the same from generation to generation, that is not the case because evolution is ongoing. **Evolution** is the process through which the characteristics of a species change over time, which can ultimately cause new species to arise.



Figure $Page 7.2.1$. The diversity of life on Earth is the result of evolution, a continuous process that is still occurring. (credit "wolf": modification of work by Gary Kramer, USFWS; credit "coral": modification of work by William Harrigan, NOAA; credit "river": modification of work by Vojtěch Dostál; credit "protozoa": modification of work by Sharon Franklin, Stephen Ausmus, USDA ARS; credit "fish" modification of work by Christian Mehlführer; credit "mushroom", "bee": modification of work by Cory Zanker; credit "tree": modification of work by Joseph Kranak)

The theory of evolution is the unifying theory of biology, meaning it is the framework within which biologists ask questions about the living world. Its power is that it provides direction for predictions about living things that are borne out in experiment after experiment. The Ukrainian-born American geneticist Theodosius Dobzhansky famously wrote that "nothing makes sense in biology except in the light of evolution." He meant that the principle that all life has evolved and diversified from a common ancestor is the foundation from which we understand all other questions in biology.

Discovering How Populations Change

The theory of evolution by natural selection describes a mechanism for how species can change over time. That species change was suggested and debated well before Darwin. The view that species were unchanging was grounded in the writings of Plato, yet there were also ancient Greeks that expressed evolutionary ideas.

In the eighteenth century, ideas about the evolution of animals were reintroduced by the various naturalists. At the same time, James Hutton, the Scottish naturalist, proposed that geological change occurred gradually by the accumulation of small changes from processes (over long periods of time) just like those happening today. This contrasted with the predominant view that the geology of the planet was a consequence of catastrophic events occurring during a relatively brief past. Hutton's view was later popularized by the geologist Charles Lyell in the nineteenth century. Lyell became a friend to Darwin and his ideas were very influential on Darwin's thinking. Lyell argued that the greater age of Earth gave more time for gradual change in species, and the process provided an analogy for gradual change in species.

Charles Darwin and Natural Selection

Natural selection as a mechanism for evolution was independently conceived of and described by two naturalists, Charles Darwin and Alfred Russell Wallace, in the mid-nineteenth century. Importantly, each spent years exploring the natural world on expeditions to the tropics. From 1831 to 1836, Darwin traveled around the world on *H.M.S. Beagle*, visiting South America, Australia, and the

southern tip of Africa. Wallace traveled to Brazil to collect insects in the Amazon rainforest from 1848 to 1852 and to the Malay Archipelago from 1854 to 1862. Darwin's journey, like Wallace's later journeys in the Malay Archipelago, included stops at several island chains, the last being the Galápagos Islands (west of Ecuador). On these islands, Darwin observed species of organisms on different islands that were clearly similar, yet had distinct differences. For example, the ground finches inhabiting the Galápagos Islands comprised several species that each had a unique beak shape (Figure $Page 7.2.2$). He observed both that these finches closely resembled another finch species on the mainland of South America and that the group of species in the Galápagos formed a graded series of beak sizes and shapes, with very small differences between the most similar. Darwin imagined that the island species might be all species modified from one original mainland species. In 1860, he wrote, "Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends."

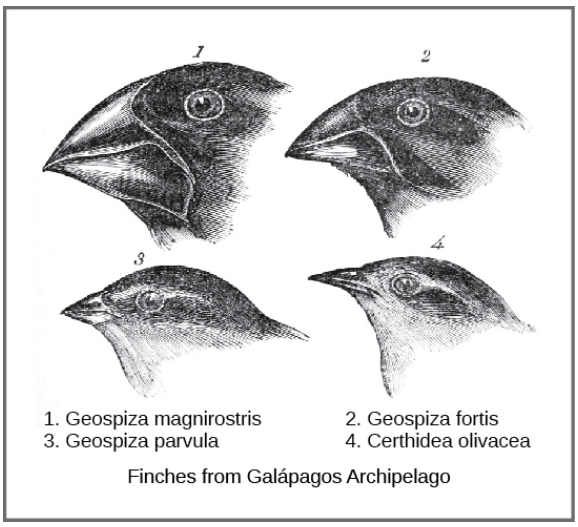


Figure $Page 7.2.2$. Darwin observed that beak shape varies among finch species. He postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources. This illustration shows the beak shapes for four species of ground finch: 1. Geospiza magnirostris (the large ground finch), 2. G. fortis (the medium ground finch), 3. G. parvula (the small tree finch), and 4. Certhidea olivacea (the green-warbler finch).

Wallace and Darwin both observed similar patterns in other organisms and independently conceived a mechanism to explain how and why such changes could take place. Darwin called this mechanism natural selection. Natural selection, Darwin argued, was an inevitable outcome of three principles that operated in nature. First, there exists variation in traits among individuals within a population, and these traits are inherited, or passed from parent to offspring. Second, more offspring are produced than are able to survive; in other words, resources for survival and reproduction are limited. And lastly, there is a competition for those resources in each generation. Out of these three principles, Darwin and Wallace reasoned that offspring with inherited characteristics that allow them to best compete for limited resources will survive and have more offspring than those individuals with variations that are less able to compete. Because characteristics are inherited, these traits will be better represented in the next generation. This will lead to change in populations over generations in a process that Darwin called "**descent with modification**." In sum, we can define **natural selection** as a process the causes beneficial traits to become more common in a population over time, causing the population to evolve.

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(a) (b)

Figure $Page 7.2.3$. (a) Charles Darwin and (b) Alfred Wallace wrote scientific papers on natural selection that were presented together before the Linnean Society in 1858.

Papers by Darwin and Wallace (Figure $Page 7.2.3$) presenting the idea of natural selection were read together in 1858 before the Linnaean Society in London. The following year Darwin's book, *On the Origin of Species*, was published, which outlined in considerable detail his arguments for evolution by natural selection.

Natural selection can only take place if there is **variation**, or differences, among individuals in a population. Importantly, these differences must have some genetic basis, otherwise natural selection would not lead to change in the next generation because there would be no way to transmit those traits from one generation to the next.

Genetic diversity in a population comes from two main sources: mutation and sexual reproduction. Mutation, a permanent change in DNA sequence is the ultimate source of new genetic variation in any population. An individual that has a mutated gene might have a different trait than other individuals in the population. Without variation in traits, nature would not be able to select the traits that are best adapted for the organisms' environment at that particular time.

Evolutionary change in action

The development of antibiotic resistant bacteria is an example of evolution through natural selection and it has been directly observed by scientists. How does this happen? Imagine a person that has a bacterial infection: their body is being attacked by billions of bacteria. Because there is genetic variation in populations, some individual bacteria may already possess traits that allow them to tolerate antibiotic drugs. When the infected person is prescribed antibiotics, the drug attacks and kills the entire population, except for those bacteria that can resist the drug. These bacteria survive because they had a trait that was beneficial and thus nature selected for it. The surviving population will all be resistant to the drug and continue to reproduce, multiple, and pass down that beneficial trait to all offspring. The population has now evolved because all individuals have the antibiotic-resistant trait, whereas before it was rare. It is important to realize that evolution occurs at the population level and is reliant upon genetic variation that was already present. Without that variation, there is nothing for nature to select for. The rise and spread of antibiotic resistant bacteria is an emerging environmental issue and will be discussed in a later chapter.

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Page 7.3: Importance of Biodiversity

The Biodiversity Crisis

Biologists estimate that species extinctions are currently 500–1000 times the normal, or background, rate seen previously in Earth's history. The current high rates will cause a precipitous decline in the biodiversity of the planet in the next century or two. The loss of biodiversity will include many species we know today. Although it is sometimes difficult to predict which species will become extinct, many are listed as **endangered** (at great risk of extinction). However, many extinctions will affect species that biologist have not yet discovered. Most of these "invisible" species that will become extinct currently live in tropical rainforests like those of the Amazon basin. These rainforests are the most diverse ecosystems on the planet and are being destroyed rapidly by deforestation. Between 1970 and 2011, almost 20 percent of the Amazon rainforest was lost.



Figure $Page 7.3.1$. This tropical lowland rainforest in Madagascar is an example of a high biodiversity habitat. This particular location is protected within a national forest, yet only 10 percent of the original coastal lowland forest remains, and research suggests half the original biodiversity has been lost. (credit: Frank Vassen)

Biodiversity is a broad term for biological variety, and it can be measured at a number of organizational levels. Traditionally, ecologists have measured biodiversity by taking into account both the number of species and the number of individuals of each species (known as **relative abundance**). However, biologists are using different measures of biodiversity, including genetic diversity, to help focus efforts to preserve the biologically and technologically important elements of biodiversity.

Biodiversity loss refers to the reduction of biodiversity due to displacement or extinction of species. The loss of a particular individual species may seem unimportant to some, especially if it is not a charismatic species like the Bengal tiger or the bottlenose dolphin. However, the current accelerated extinction rate means the loss of tens of thousands of species within our lifetimes. Much of this loss is occurring in tropical rainforests like the one pictured in Figure $Page 7.3.1$, which are very high in biodiversity but are being cleared for timber and agriculture. This is likely to have dramatic effects on human welfare through the collapse of ecosystems.

Biologists recognize that human populations are embedded in ecosystems and are dependent on them, just as is every other species on the planet. Agriculture began after early hunter-gatherer societies first settled in one place and heavily modified their immediate environment. This cultural transition has made it difficult for humans to recognize their dependence on living things other than crops and domesticated animals on the planet. Today our technology smooths out the harshness of existence and allows many of us to live longer, more comfortable lives, but ultimately the human species cannot exist without its surrounding ecosystems. Our ecosystems provide us with food, medicine, clean air and water, recreation, and spiritual and aesthetical inspiration.

Types of Biodiversity

A common meaning of biodiversity is simply the number of species in a location or on Earth; for example, the American Ornithologists' Union lists 2078 species of birds in North and Central America. This is one measure of the bird biodiversity on the continent. More sophisticated measures of diversity take into account the relative abundances of species. For example, a forest with 10 equally common species of trees is more diverse than a forest that has 10 species of trees wherein just one of those species

makes up 95 percent of the trees. Biologists have also identified alternate measures of biodiversity, some of which are important in planning how to preserve biodiversity.

Genetic diversity is one alternate concept of biodiversity. **Genetic diversity** is the raw material for evolutionary adaptation in a species and is represented by the variety of genes present within a population. A species' potential to adapt to changing environments or new diseases depends on this genetic diversity.

It is also useful to define **ecosystem diversity**: the number of different ecosystems on Earth or in a geographical area. The loss of an ecosystem means the loss of the interactions between species and the loss of biological productivity that an ecosystem is able to create. An example of a largely extinct ecosystem in North America is the prairie ecosystem (Figure *Page*7.3.2). Prairies once spanned central North America from the boreal forest in northern Canada down into Mexico. They are now all but gone, replaced by crop fields, pasture lands, and suburban sprawl. Many of the species survive, but the hugely productive ecosystem that was responsible for creating our most productive agricultural soils is now gone. As a consequence, their soils are now being depleted unless they are maintained artificially at great expense. The decline in soil productivity occurs because the interactions in the original ecosystem have been lost.

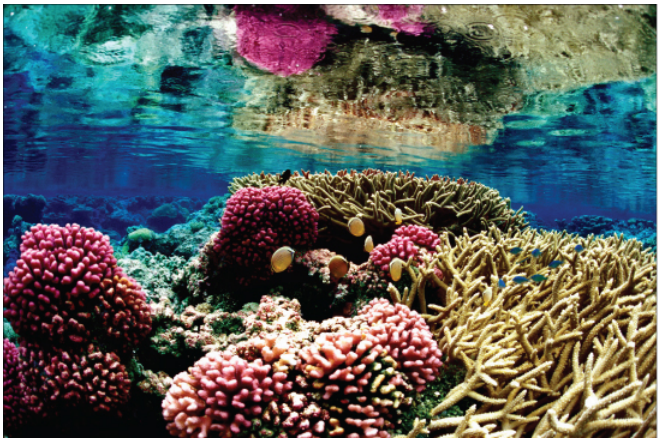




Figure *Page*7.3.2. The variety of ecosystems on Earth—from coral reef to prairie—enables a great diversity of species to exist. (credit "coral reef": modification of work by Jim Maragos, USFWS; credit: "prairie": modification of work by Jim Minnerath, USFWS)

Current Species Diversity

Despite considerable effort, knowledge of the species that inhabit the planet is limited. A recent estimate suggests that only 13% of eukaryotic species have been named (Table 1). Estimates of numbers of prokaryotic species are largely guesses, but biologists agree that science has only just begun to catalog their diversity. . Given that Earth is losing species at an accelerating pace, science knows little about what is being lost.

Table 1. This table shows the estimated number of species by taxonomic group—including both described (named and studied) and predicted (yet to be named) species.

Estimated Numbers of Described and Predicted species						
	Source: Mora et al 2011		Source: Chapman 2009		Source: Groombridge and Jenkins 2002	
	Described	Predicted	Described	Predicted	Described	Predicted
Animals	1,124,516	9,920,000	1,424,153	6,836,330	1,225,500	10,820,000
Photosynthetic protists	17,892	34,900	25,044	200,500	—	—
Fungi	44,368	616,320	98,998	1,500,000	72,000	1,500,000
Plants	224,244	314,600	310,129	390,800	270,000	320,000
Non-photosynthetic protists	16,236	72,800	28,871	1,000,000	80,000	600,000
Prokaryotes	—	—	10,307	1,000,000	10,175	—
Total	1,438,769	10,960,000	1,897,502	10,897,630	1,657,675	13,240,000

There are various initiatives to catalog described species in accessible and more organized ways, and the internet is facilitating that effort. Nevertheless, at the current rate of species description, which according to the State of Observed Species[1] reports is 17,000–20,000 new species a year, it would take close to 500 years to describe all of the species currently in existence. The task, however, is becoming increasingly impossible over time as extinction removes species from Earth faster than they can be described.

Naming and counting species may seem an unimportant pursuit given the other needs of humanity, but it is not simply an accounting. Describing species is a complex process by which biologists determine an organism's unique characteristics and whether or not that organism belongs to any other described species. It allows biologists to find and recognize the species after the initial discovery to follow up on questions about its biology. That subsequent research will produce the discoveries that make the species valuable to humans and to our ecosystems. Without a name and description, a species cannot be studied in depth and in a coordinated way by multiple scientists.

Patterns of Biodiversity

Biodiversity is not evenly distributed on the planet. Lake Victoria contained almost 500 species of cichlids (just one family of fishes that are present in the lake) before the introduction of an exotic species in the 1980s and 1990s caused a mass extinction. All of these species were found only in Lake Victoria, which is to say they were endemic. **Endemic species** are found in only one location. For example, the blue jay is endemic to North America, while the Barton Springs salamander is endemic to the mouth of one spring in Austin, Texas. Endemic species with highly restricted distributions, like the Barton Springs salamander, are particularly vulnerable to extinction.

Lake Huron contains about 79 species of fish, all of which are found in many other lakes in North America. What accounts for the difference in diversity between Lake Victoria and Lake Huron? Lake Victoria is a tropical lake, while Lake Huron is a temperate lake. Lake Huron in its present form is only about 7,000 years old, while Lake Victoria in its present form is about 15,000 years old. These two factors, latitude and age, are two of several hypotheses biogeographers have suggested to explain biodiversity patterns on Earth.

Biogeography is the study of the distribution of the world's species both in the past and in the present. The work of biogeographers is critical to understanding our physical environment, how the environment affects species, and how changes in environment impact the distribution of a species.

There are three main fields of study under the heading of biogeography: ecological biogeography, historical biogeography (called paleobiogeography), and conservation biogeography. Ecological biogeography studies the current factors affecting the distribution of plants and animals. Historical biogeography, as the name implies, studies the past distribution of species. Conservation

biogeography, on the other hand, is focused on the protection and restoration of species based upon the known historical and current ecological information.

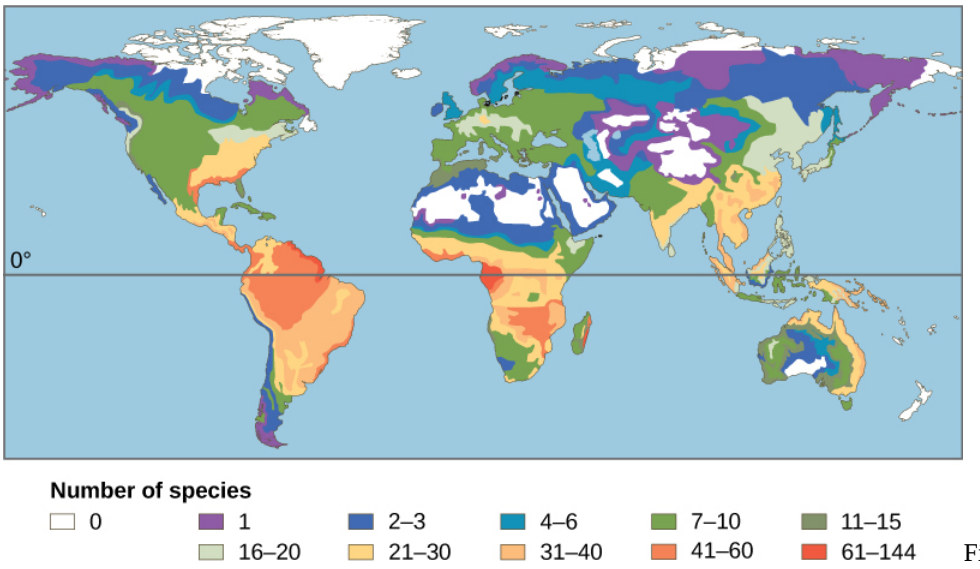


Figure $Page 7.3.3$. This map illustrates the number of amphibian species across the globe and shows the trend toward higher biodiversity at lower latitudes. A similar pattern is observed for most taxonomic groups.

One of the oldest observed patterns in ecology is that biodiversity typically increases as latitude declines. In other words, biodiversity increases closer to the equator (Figure $Page 7.3.3$).

It is not yet clear why biodiversity increases closer to the equator, but hypotheses include the greater age of the ecosystems in the tropics versus temperate regions, which were largely devoid of life or drastically impoverished during the last ice age. The greater age provides more time for **speciation,** the evolutionary process of creating new species. Another possible explanation is the greater energy the tropics receive from the sun. But scientists have not been able to explain how greater energy input could translate into more species. The complexity of tropical ecosystems may promote speciation by increasing the habitat complexity, thus providing more ecological niches. Lastly, the tropics have been perceived as being more stable than temperate regions, which have a pronounced climate and day-length seasonality. The stability of tropical ecosystems might promote speciation. Regardless of the mechanisms, it is certainly true that biodiversity is greatest in the tropics. There are also high numbers of endemic species.

Importance of Biodiversity

Loss of biodiversity may have reverberating consequences on ecosystems because of the complex interrelations among species. For example, the extinction of one species may cause the extinction of another. Biodiversity is important to the survival and welfare of human populations because it has impacts on our health and our ability to feed ourselves through agriculture and harvesting populations of wild animals.

Human Health

Many medications are derived from natural chemicals made by a diverse group of organisms. For example, many plants produce compounds meant to protect the plant from insects and other animals that eat them. Some of these compounds also work as human medicines. Contemporary societies that live close to the land often have a broad knowledge of the medicinal uses of plants growing in their area. For centuries in Europe, older knowledge about the medical uses of plants was compiled in herbals—books that identified the plants and their uses. Humans are not the only animals to use plants for medicinal reasons. The other great apes, orangutans, chimpanzees, bonobos, and gorillas have all been observed self-medicating with plants.

Modern pharmaceutical science also recognizes the importance of these plant compounds. Examples of significant medicines derived from plant compounds include aspirin, codeine, digoxin, atropine, and vincristine (Figure $Page 7.3.4$). Many medications were once derived from plant extracts but are now synthesized. It is estimated that, at one time, 25 percent of modern drugs contained at least one plant extract. That number has probably decreased to about 10 percent as natural plant ingredients are

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replaced by synthetic versions of the plant compounds. Antibiotics, which are responsible for extraordinary improvements in health and lifespans in developed countries, are compounds largely derived from fungi and bacteria.



Figure $Page 7.3.4$. Catharanthus roseus, the Madagascar periwinkle, has various medicinal properties. Among other uses, it is a source of vincristine, a drug used in the treatment of lymphomas. (credit: Forest and Kim Starr)

In recent years, animal venoms and poisons have excited intense research for their medicinal potential. By 2007, the FDA had approved five drugs based on animal toxins to treat diseases such as hypertension, chronic pain, and diabetes. Another five drugs are undergoing clinical trials and at least six drugs are being used in other countries. Other toxins under investigation come from mammals, snakes, lizards, various amphibians, fish, snails, octopuses, and scorpions.

Aside from representing billions of dollars in profits, these medications improve people's lives. Pharmaceutical companies are actively looking for new natural compounds that can function as medicines. It is estimated that one third of pharmaceutical research and development is spent on natural compounds and that about 35 percent of new drugs brought to market between 1981 and 2002 were from natural compounds.

Finally, it has been argued that humans benefit psychologically from living in a biodiverse world. The chief proponent of this idea is famed entomologist E. O. Wilson. He argues that human evolutionary history has adapted us to living in a natural environment and that built environments generate stresses that affect human health and well-being. There is considerable research into the psychologically regenerative benefits of natural landscapes that suggest the hypothesis may hold some truth.

Agricultural

Since the beginning of human agriculture more than 10,000 years ago, human groups have been breeding and selecting crop varieties. This crop diversity matched the cultural diversity of highly subdivided populations of humans. For example, potatoes were domesticated beginning around 7,000 years ago in the central Andes of Peru and Bolivia. The people in this region traditionally lived in relatively isolated settlements separated by mountains. The potatoes grown in that region belong to seven species and the number of varieties likely is in the thousands. Each variety has been bred to thrive at particular elevations and soil and climate conditions. The diversity is driven by the diverse demands of the dramatic elevation changes, the limited movement of people, and the demands created by crop rotation for different varieties that will do well in different fields.

Potatoes are only one example of agricultural diversity. Every plant, animal, and fungus that has been cultivated by humans has been bred from original wild ancestor species into diverse varieties arising from the demands for food value, adaptation to growing conditions, and resistance to pests. The potato demonstrates a well-known example of the risks of low crop diversity: during the tragic Irish potato famine (1845–1852 AD), the single potato variety grown in Ireland became susceptible to a potato blight—wiping out the crop. The loss of the crop led to famine, death, and mass emigration. Resistance to disease is a chief benefit to maintaining crop biodiversity and lack of diversity in contemporary crop species carries similar risks. Seed companies, which are the source of most crop varieties in developed countries, must continually breed new varieties to keep up with evolving pest organisms. These same seed companies, however, have participated in the decline of the number of varieties available as they focus on selling fewer varieties in more areas of the world replacing traditional local varieties.

The ability to create new crop varieties relies on the diversity of varieties available and the availability of wild forms related to the crop plant. These wild forms are often the source of new gene variants that can be bred with existing varieties to create varieties with new attributes. Loss of wild species related to a crop will mean the loss of potential in crop improvement. Maintaining the genetic diversity of wild species related to domesticated species ensures our continued supply of food.

Since the 1920s, government agriculture departments have maintained seed banks of crop varieties as a way to maintain crop diversity. This system has flaws because over time seed varieties are lost through accidents and there is no way to replace them. In 2008, the Svalbard Global seed Vault, located on Spitsbergen island, Norway, (Figure) began storing seeds from around the world as a backup system to the regional seed banks. If a regional seed bank stores varieties in Svalbard, losses can be replaced from Svalbard should something happen to the regional seeds. The Svalbard seed vault is deep into the rock of the arctic island. Conditions within the vault are maintained at ideal temperature and humidity for seed survival, but the deep underground location of the vault in the arctic means that failure of the vault's systems will not compromise the climatic conditions inside the vault.


Figure $Page 7.3.5$. The Svalbard Global Seed Vault is a storage facility for seeds of Earth's diverse crops. (credit: Mari Tefre, Svalbard Global Seed Vault)

Although crops are largely under our control, our ability to grow them is dependent on the biodiversity of the ecosystems in which they are grown. That biodiversity creates the conditions under which crops are able to grow through what are known as ecosystem services—valuable conditions or processes that are carried out by an ecosystem. Crops are not grown, for the most part, in built environments. They are grown in soil. Although some agricultural soils are rendered sterile using controversial pesticide treatments, most contain a huge diversity of organisms that maintain nutrient cycles—breaking down organic matter into nutrient compounds that crops need for growth. These organisms also maintain soil texture that affects water and oxygen dynamics in the soil that are necessary for plant growth. Replacing the work of these organisms in forming arable soil is not practically possible. These kinds of processes are called ecosystem services. They occur within ecosystems, such as soil ecosystems, as a result of the diverse metabolic activities of the organisms living there, but they provide benefits to human food production, drinking water availability, and breathable air.

Other key ecosystem services related to food production are plant pollination and crop pest control. It is estimated that honeybee pollination within the United States brings in $1.6 billion per year; other pollinators contribute up to $6.7 billion. Over 150 crops in the United States require pollination to produce. Many honeybee populations are managed by beekeepers who rent out their hives' services to farmers. Honeybee populations in North America have been suffering large losses caused by a syndrome known as colony collapse disorder, a new phenomenon with an unclear cause. Other pollinators include a diverse array of other bee species and various insects and birds. Loss of these species would make growing crops requiring pollination impossible, increasing dependence on other crops.

Finally, humans compete for their food with crop pests, most of which are insects. Pesticides control these competitors, but these are costly and lose their effectiveness over time as pest populations adapt. They also lead to collateral damage by killing non-pest species as well as beneficial insects like honeybees, and risking the health of agricultural workers and consumers. Moreover, these pesticides may migrate from the fields where they are applied and do damage to other ecosystems like streams, lakes, and even the ocean. Ecologists believe that the bulk of the work in removing pests is actually done by predators and parasites of those pests, but the impact has not been well studied. A review found that in 74 percent of studies that looked for an effect of landscape complexity (forests and fallow fields near to crop fields) on natural enemies of pests, the greater the complexity, the greater the effect of pest-

suppressing organisms. Another experimental study found that introducing multiple enemies of pea aphids (an important alfalfa pest) increased the yield of alfalfa significantly. This study shows that a diversity of pests is more effective at control than one single pest. Loss of diversity in pest enemies will inevitably make it more difficult and costly to grow food. The world's growing human population faces significant challenges in the increasing costs and other difficulties associated with producing food.

Wild Food Sources

In addition to growing crops and raising food animals, humans obtain food resources from wild populations, primarily wild fish populations. For about one billion people, aquatic resources provide the main source of animal protein. But since 1990, production from global fisheries has declined. Despite considerable effort, few fisheries on Earth are managed sustainability.

Fishery extinctions rarely lead to complete extinction of the harvested species, but rather to a radical restructuring of the marine ecosystem in which a dominant species is so over-harvested that it becomes a minor player, ecologically. In addition to humans losing the food source, these alterations affect many other species in ways that are difficult or impossible to predict. The collapse of fisheries has dramatic and long-lasting effects on local human populations that work in the fishery. In addition, the loss of an inexpensive protein source to populations that cannot afford to replace it will increase the cost of living and limit societies in other ways. In general, the fish taken from fisheries have shifted to smaller species and the larger species are overfished. The ultimate outcome could clearly be the loss of aquatic systems as food sources.

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Page 7.4: Threats to Biodiversity

The core threat to biodiversity on the planet, and therefore a threat to human welfare, is the combination of human population growth and the resources used by that population. The human population requires resources to survive and grow, and many of those resources are being removed unsustainably from the environment. The three greatest proximate threats to biodiversity are habitat loss, overharvesting, and introduction of exotic species. The first two of these are a direct result of human population growth and resource use. The third results from increased mobility and trade. A fourth major cause of extinction, **anthropogenic** (human-caused) climate change, has not yet had a large impact, but it is predicted to become significant during this century. Global climate change is also a consequence of human population needs for energy and the use of fossil fuels to meet those needs (Figure *Page*7.4.1). Environmental issues, such as toxic pollution, have specific targeted effects on species, but are not generally seen as threats at the magnitude of the others.

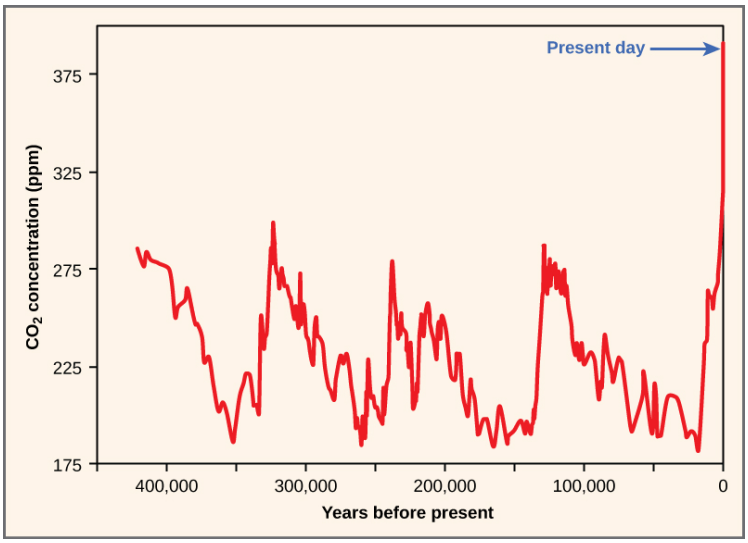


Figure *Page*7.4.1. Atmospheric carbon dioxide levels fluctuate in a cyclical manner. However, the burning of fossil fuels in recent history has caused a dramatic increase in the levels of carbon dioxide in the Earth's atmosphere, which have now reached levels never before seen on Earth. Scientists predict that the addition of this "greenhouse gas" to the atmosphere is resulting in climate change that will significantly impact biodiversity in the coming century.

Habitat Loss

Humans rely on technology to modify their environment and make it habitable. Other species cannot do this. Elimination of their habitat—whether it is a forest, coral reef, grassland, or flowing river—will kill the individuals in the species. Remove the entire habitat and the species will become extinct, unless they are among the few species that do well in human-built environments. Human destruction of habitats (**habitat** generally refers to the part of the ecosystem required by a particular species) accelerated in the latter half of the twentieth century.

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Figure $Page 7.4.2$. An oil palm plantation in Sabah province Borneo, Malaysia, replaces native forest habitat that a variety of species depended on to live. (credit: Lian Pin Koh)

Consider the exceptional biodiversity of Sumatra: it is home to one species of orangutan, a species of critically endangered elephant, and the Sumatran tiger, but half of Sumatra's forest is now gone. The neighboring island of Borneo, home to the other species of orangutan, has lost a similar area of forest. Forest loss continues in protected areas of Borneo. The orangutan in Borneo is listed as endangered by the International Union for Conservation of Nature (IUCN), but it is simply the most visible of thousands of species that will not survive the disappearance of the forests of Borneo. The forests are removed for timber and to plant palm oil plantations (Figure $Page 7.4.2$). Palm oil is used in many products including food products, cosmetics, and biodiesel in Europe. A 5-year estimate of global forest cover loss for the years from 2000 to 2005 was 3.1%. Much loss (2.4%) occurred in the tropics where forest loss is primarily from timber extraction. These losses certainly also represent the extinction of species unique to those areas.

BIOLOGY IN ACTION: Preventing Habitat Destruction with Wise Wood Choices

Most consumers do not imagine that the home improvement products they buy might be contributing to habitat loss and species extinctions. Yet the market for illegally harvested tropical timber is huge, and the wood products often find themselves in building supply stores in the United States. One estimate is that up to 10% of the imported timber in the United States, which is the world's largest consumer of wood products, is illegally logged. In 2006, this amounted to $3.6 billion in wood products. Most of the illegal products are imported from countries that act as intermediaries and are not the originators of the wood.

How is it possible to determine if a wood product, such as flooring, was harvested sustainably or even legally? The Forest Stewardship Council (FSC) certifies sustainably harvested forest products. Looking for their certification on flooring and other hardwood products is one way to ensure that the wood has not been taken illegally from a tropical forest. There are certifications other than the FSC, but these are run by timber companies, thus creating a conflict of interest. Another approach is to buy domestic wood species. While it would be great if there was a list of legal versus illegal woods, it is not that simple. Logging and forest management laws vary from country to country; what is illegal in one country may be legal in another. Where and how a product is harvested and whether the forest from which it comes is being sustainably maintained all factor into whether a wood product will be certified by the FSC. It is always a good idea to ask questions about where a wood product came from and how the supplier knows that it was harvested legally.

Habitat destruction can affect ecosystems other than forests. Rivers and streams are important ecosystems and are frequently the target of habitat modification. Damming of rivers affects flow and access to habitat. Altering a flow regime can reduce or eliminate populations that are adapted to seasonal changes in flow. For example, an estimated 91% of riverways in the United States have been modified with damming or stream bank modification. Many fish species in the United States, especially rare species or species with restricted distributions, have seen declines caused by river damming and habitat loss. Research has confirmed that species of amphibians that must carry out parts of their life cycles in both aquatic and terrestrial habitats are at greater risk of population declines and extinction because of the increased likelihood that one of their habitats or access between them will be lost. This is of particular concern because amphibians have been declining in numbers and going extinct more rapidly than many other groups for a variety of possible reasons.

Overharvesting

Overharvesting is a serious threat to many species, but particularly to aquatic species. There are many examples of regulated fisheries (including hunting of marine mammals and harvesting of crustaceans and other species) monitored by fisheries scientists that have nevertheless collapsed. The western Atlantic cod fishery is the most spectacular recent collapse. While it was a hugely productive fishery for 400 years, the introduction of modern factory trawlers in the 1980s and the pressure on the fishery led to it becoming unsustainable. The causes of fishery collapse are both economic and political in nature.

Most fisheries are managed as a common resource, available to anyone willing to fish, even when the fishing territory lies within a country's territorial waters. Common resources are subject to an economic pressure known as the tragedy of the commons, in which fishers have little motivation to exercise restraint in harvesting a fishery when they do not own the fishery. The general outcome of harvests of resources held in common is their overexploitation. While large fisheries are regulated to attempt to avoid this pressure, it still exists in the background. This overexploitation is exacerbated when access to the fishery is open and unregulated and when technology gives fishers the ability to overfish. In a few fisheries, the biological growth of the resource is less than the potential growth of the profits made from fishing if that time and money were invested elsewhere. In these cases—whales are an example—economic forces will drive toward fishing the population to extinction.

Coral reefs are extremely diverse marine ecosystems that face peril from several processes. Reefs are home to 1/3 of the world's marine fish species—about 4000 species—despite making up only one percent of marine habitat. Most home marine aquaria house coral reef species that are wild-caught organisms—not cultured organisms. Although no marine species is known to have been driven extinct by the pet trade, there are studies showing that populations of some species have declined in response to harvesting, indicating that the harvest is not sustainable at those levels. There are also concerns about the effect of the pet trade on some terrestrial species such as turtles, amphibians, birds, plants, and even the orangutans.



Figure $Page 7.4.3$. Harvesting of pangolins for their scales and meat, and as curiosities, has led to a drastic decline in population size for this fascinating creature. *This work by David Brossard is licensed under CC BY 4.0*

Bush meat is the generic term used for wild animals killed for food. Hunting is practiced throughout the world, but hunting practices, particularly in equatorial Africa and parts of Asia, are believed to threaten several species with extinction. Traditionally, bush meat in Africa was hunted to feed families directly. However, recent commercialization of the practice now has bush meat available in grocery stores, which has increased harvest rates to the level of unsustainability. Additionally, human population growth has increased the need for protein foods that are not being met from agriculture. Species threatened by the bush meat trade are mostly mammals including many monkeys and the great apes living in the Congo basin.

Invasive Species

Exotic species are species that have been intentionally or unintentionally introduced by humans into an ecosystem in which they did not evolve. Human transportation of people and goods, including the intentional transport of organisms for trade, has dramatically increased the introduction of species into new ecosystems. These new introductions are sometimes at distances that are well beyond the capacity of the species to ever travel itself and outside the range of the species' natural predators.

Most exotic species introductions probably fail because of the low number of individuals introduced or poor adaptation to the ecosystem they enter. Some species, however, have characteristics that can make them especially successful in a new ecosystem. These exotic species often undergo dramatic population increases in their new habitat and reset the ecological conditions in the new

environment, threatening the species that exist there. When this happens, the exotic species also becomes an **invasive species**. Invasive species can threaten other species through competition for resources, predation, or disease.

Lakes and islands are particularly vulnerable to extinction threats from introduced species. In Lake Victoria, the intentional introduction of the Nile perch was largely responsible for the extinction of about 200 species of cichlids. The accidental introduction of the brown tree snake via aircraft (Figure $Page7.4.4$) from the Solomon Islands to Guam in 1950 has led to the extinction of three species of birds and three to five species of reptiles endemic to the island. Several other species are still threatened. The brown tree snake is adept at exploiting human transportation as a means to migrate; one was even found on an aircraft arriving in Corpus Christi, Texas. Constant vigilance on the part of airport, military, and commercial aircraft personnel is required to prevent the snake from moving from Guam to other islands in the Pacific, especially Hawaii. Islands do not make up a large area of land on the globe, but they do contain a disproportionate number of endemic species because of their isolation from mainland ancestors.

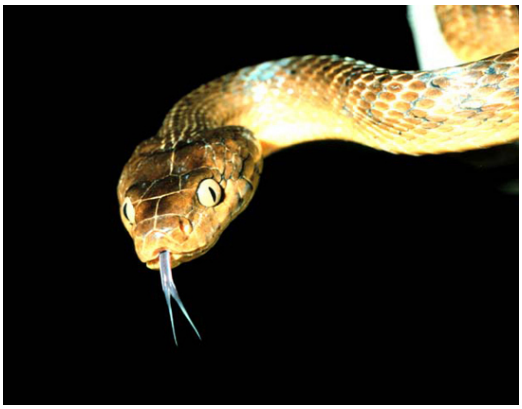


Figure $Page7.4.4$. The brown tree snake, Boiga irregularis, is an exotic species that has caused numerous extinctions on the island of Guam since its accidental introduction in 1950. (credit: NPS)

Many introductions of aquatic species, both marine and freshwater, have occurred when ships have dumped ballast water taken on at a port of origin into waters at a destination port. Water from the port of origin is pumped into tanks on a ship empty of cargo to increase stability. The water is drawn from the ocean or estuary of the port and typically contains living organisms such as plant parts, microorganisms, eggs, larvae, or aquatic animals. The water is then pumped out before the ship takes on cargo at the destination port, which may be on a different continent. The zebra mussel was introduced to the Great Lakes from Europe prior to 1988 in ballast water. The zebra mussels in the Great Lakes have created millions of dollars in clean-up costs to maintain water intakes and other facilities. The mussels have also altered the ecology of the lakes dramatically. They threaten native mollusk populations, but have also benefited some species, such as smallmouth bass. The mussels are filter feeders and have dramatically improved water clarity, which in turn has allowed aquatic plants to grow along shorelines, providing shelter for young fish where it did not exist before. The European green crab, *Carcinus maenas*, was introduced to San Francisco Bay in the late 1990s, likely in ship ballast water, and has spread north along the coast to Washington. The crabs have been found to dramatically reduce the abundance of native clams and crabs with resulting increases in the prey species of those native crabs.

Invading exotic species can also be disease organisms. It now appears that the global decline in amphibian species recognized in the 1990s is, in some part, caused by the fungus *Batrachochytrium dendrobatidis*, which causes the disease chytridiomycosis (Figure $Page7.4.5$). There is evidence that the fungus is native to Africa and may have been spread throughout the world by transport of a commonly used laboratory and pet species: the African clawed frog, *Xenopus laevis*. It may well be that biologists themselves are responsible for spreading this disease worldwide. The North American bullfrog, *Rana catesbeiana*, which has also been widely introduced as a food animal but which easily escapes captivity, survives most infections of *B. dendrobatidis* and can act as a reservoir for the disease.



Figure $Page$7.4.5. This Limosa harlequin frog (Atelopus limosus), an endangered species from Panama, died from a fungal disease called chytridiomycosis. The red lesions are symptomatic of the disease. (credit: Brian Gratwicke)

Early evidence suggests that another fungal pathogen, *Geomyces destructans*, introduced from Europe is responsible for white-nose syndrome, which infects cave-hibernating bats in eastern North America and has spread from a point of origin in western New York State (Figure $Page$7.4.6). The disease has decimated bat populations and threatens extinction of species already listed as endangered: the Indiana bat, *Myotis sodalis*, and potentially the Virginia big-eared bat, *Corynorhinus townsendii virginianus*. How the fungus was introduced is unknown, but one logical presumption would be that recreational cavers unintentionally brought the fungus on clothes or equipment from Europe.



Figure $Page$7.4.6. This little brown bat in Greeley Mine, Vermont, March 26, 2009, was found to have white-nose syndrome. (credit: modification of work by Marvin Moriarty, USFWS).

Climate Change

Climate change, and specifically the anthropogenic warming trend presently underway, is recognized as a major extinction threat, particularly when combined with other threats such as habitat loss. Anthropogenic warming of the planet has been observed and is due to past and continuing emission of greenhouse gases, primarily carbon dioxide and methane, into the atmosphere caused by the burning of fossil fuels and deforestation. Scientists overwhelmingly agree the present warming trend is caused by humans and some of the likely effects include dramatic and dangerous climate changes in the coming decades. Scientists predict that climate change will alter regional climates, including rainfall and snowfall patterns, making habitats less hospitable to the species living in

them. The warming trend will shift colder climates toward the north and south poles, forcing species to move (if possible) with their adapted climate norms.

The shifting ranges will impose new competitive regimes on species as they find themselves in contact with other species not present in their historic range. One such unexpected species contact is between polar bears and grizzly bears. Previously, these two species had separate ranges. Now, their ranges are overlapping and there are documented cases of these two species mating and producing viable offspring. Changing climates also throw off the delicate timing adaptations that species have to seasonal food resources and breeding times. Scientists have already documented many contemporary mismatches to shifts in resource availability and timing.

Other shifts in range have been observed. For example, one study indicates that European bird species ranges have moved 91 km (56.5 mi) northward, on average. The same study suggested that the optimal shift based on warming trends was double that distance, suggesting that the populations are not moving quickly enough. Range shifts have also been observed in plants, butterflies, other insects, freshwater fishes, reptiles, amphibians, and mammals.

Climate gradients will also move up mountains, eventually crowding species higher in altitude and eliminating the habitat for those species adapted to the highest elevations. Some climates will completely disappear. The rate of warming appears to be accelerated in the arctic, which is recognized as a serious threat to polar bear populations that require sea ice to hunt seals during the winter months. Seals are a critical source of protein for polar bears. A trend to decreasing sea ice coverage has occurred since observations began in the mid-twentieth century. The rate of decline observed in recent years is far greater than previously predicted by climate models.



Figure *Page*7.4.7. The effect of global warming can be seen in the continuing retreat of Grinnell Glacier. The mean annual temperature in Glacier National Park has increased 1.33°C since 1900. The loss of a glacier results in the loss of summer meltwaters, sharply reducing seasonal water supplies and severely affecting local ecosystems. (credit: USGS, GNP Archives)

Finally, global warming will raise ocean levels due to meltwater from glaciers and the greater volume occupied by warmer water. Shorelines will be inundated, reducing island size, which will have an effect on some species, and a number of islands will disappear entirely. Additionally, the gradual melting and subsequent refreezing of the poles, glaciers, and higher elevation mountains—a cycle that has provided freshwater to environments for centuries—will be altered. This could result in an overabundance of salt water and a shortage of fresh water.

Suggested Supplementary Reading:

Hall. S. 2017. Could Genetic Engineering Save the Galápagos? *Scientific American*. December. p. 48-57.

This article explores the destructive nature of invasive species in the Galápagos Islands. Traditional efforts to eradicate invasive species, such as rats, can be expensive and cause ecological harm by the widespread distribution of poison. An alternate approach is genetic engineering in the form of a "gene drive", an emerging technique that could be better – or worse – for the environment.

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Page 7.5: Preserving Biodiversity

Preserving biodiversity is an extraordinary challenge that must be met by greater understanding of biodiversity itself, changes in human behavior and beliefs, and various preservation strategies.

Change in Biodiversity through Time

The number of species on the planet, or in any geographical area, is the result of an equilibrium of two evolutionary processes that are ongoing: speciation and extinction. When speciation rates begin to outstrip extinction rates, the number of species will increase. Likewise, the reverse is true when extinction rates begin to overtake speciation rates. Throughout the history of life on Earth, as reflected in the fossil record, these two processes have fluctuated to a greater or lesser extent, sometimes leading to dramatic changes in the number of species on the planet as reflected in the fossil record (Figure $Page 7.5.1$).

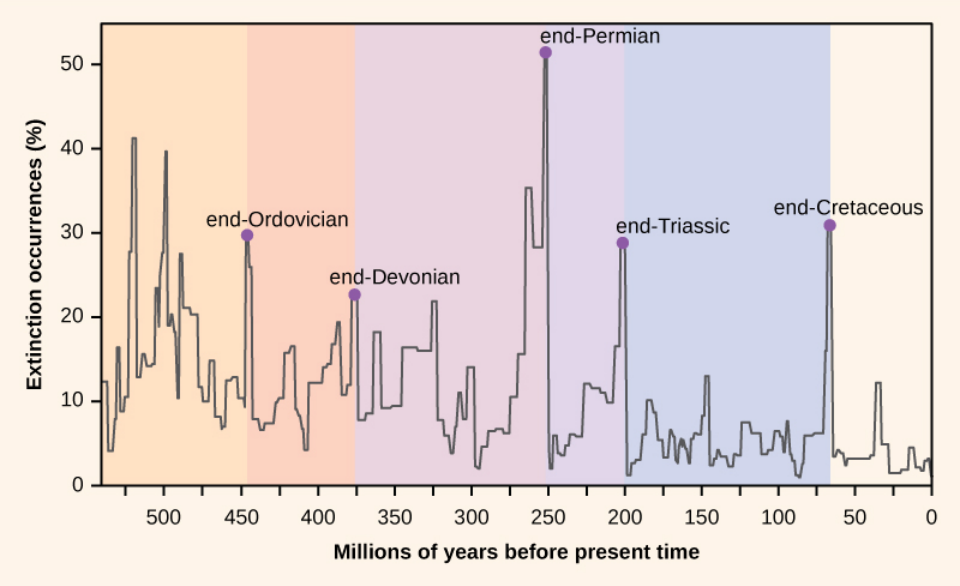


Figure $Page 7.5.1$. Extinction intensity as reflected in the fossil record has fluctuated throughout Earth's history. Sudden and dramatic losses of biodiversity, called mass extinctions, have occurred five times.

Paleontologists have identified five layers in the fossil record that appear to show sudden and dramatic losses in biodiversity. These are called **mass extinctions**and are characterized by more than half of all species disappearing from the fossil record. There are many lesser, yet still dramatic, extinction events, but the five mass extinctions have attracted the most research into their causes. An argument can be made that the five mass extinctions are only the five most extreme events in a continuous series of large extinction events throughout the fossil record (since 542 million years ago). The most recent extinction in geological time, about 65 million years ago, saw the disappearance of most dinosaurs species (except birds) and many other species. Most scientists now agree the main cause of this extinction was the impact of a large asteroid in the present-day Yucatán Peninsula and the subsequent energy release and global climate changes caused by dust ejected into the atmosphere.

Recent and Current Extinction Rates

Many biologists say that we are currently experience a sixth mass extinction and it mostly has to do with the activities of humans. There are numerous recent extinctions of individual species that are recorded in human writings. Most of these are coincident with the expansion of the European colonies since the 1500s.

One of the earlier and popularly known examples is the dodo bird. The dodo bird lived in the forests of Mauritius, an island in the Indian Ocean. The dodo bird became extinct around 1662. It was hunted for its meat by sailors and was easy prey because the dodo, which did not evolve with humans, would approach people without fear. Introduced pigs, rats, and dogs brought to the island by European ships also killed dodo young and eggs (Figure $Page 7.5.2$).

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Figure $Page 7.5.2$. The dodo bird was hunted to extinction around 1662. (credit: Ed Uthman, taken in Natural History Museum, London, England)

Steller's sea cow became extinct in 1768; it was related to the manatee and probably once lived along the northwest coast of North America. Steller's sea cow was discovered by Europeans in 1741, and it was hunted for meat and oil. A total of 27 years elapsed between the sea cow's first contact with Europeans and extinction of the species. The last Steller's sea cow was killed in 1768. In another example, the last living passenger pigeon died in a zoo in Cincinnati, Ohio, in 1914. This species had once migrated in the millions but declined in numbers because of overhunting and loss of habitat through the clearing of forests for farmland.

These are only a few of the recorded extinctions in the past 500 years. The International Union for Conservation of Nature (IUCN) keeps a list of extinct and endangered species called the Red List. The list is not complete, but it describes 380 vertebrates that became extinct after 1500 AD, 86 of which were driven extinct by overhunting or overfishing.

Estimates of Present-day Extinction Rates

Estimates of extinction rates are hampered by the fact that most extinctions are probably happening without being observed. The extinction of a bird or mammal is often noticed by humans, especially if it has been hunted or used in some other way. But there are many organisms that are less noticeable to humans (not necessarily of less value) and many that are undescribed.

The **background extinction rate** is estimated to be about 1 per million species years (E/MSY). One "species year" is one species in existence for one year. One million species years could be one species persisting for one million years, or a million species persisting for one year. If it is the latter, then one extinction per million species years would be one of those million species becoming extinct in that year. For example, if there are 10 million species in existence, then we would expect 10 of those species to become extinct in a year. This is the background rate.

One contemporary extinction-rate estimate uses the extinctions in the written record since the year 1500. For birds alone, this method yields an estimate of 26 E/MSY, almost three times the background rate. However, this value may be underestimated for three reasons. First, many existing species would not have been described until much later in the time period and so their loss would have gone unnoticed. Second, we know the number is higher than the written record suggests because now extinct species are being described from skeletal remains that were never mentioned in written history. And third, some species are probably already extinct even though conservationists are reluctant to name them as such. Taking these factors into account raises the estimated extinction rate to nearer 100 E/MSY. The predicted rate by the end of the century is 1500 E/MSY.

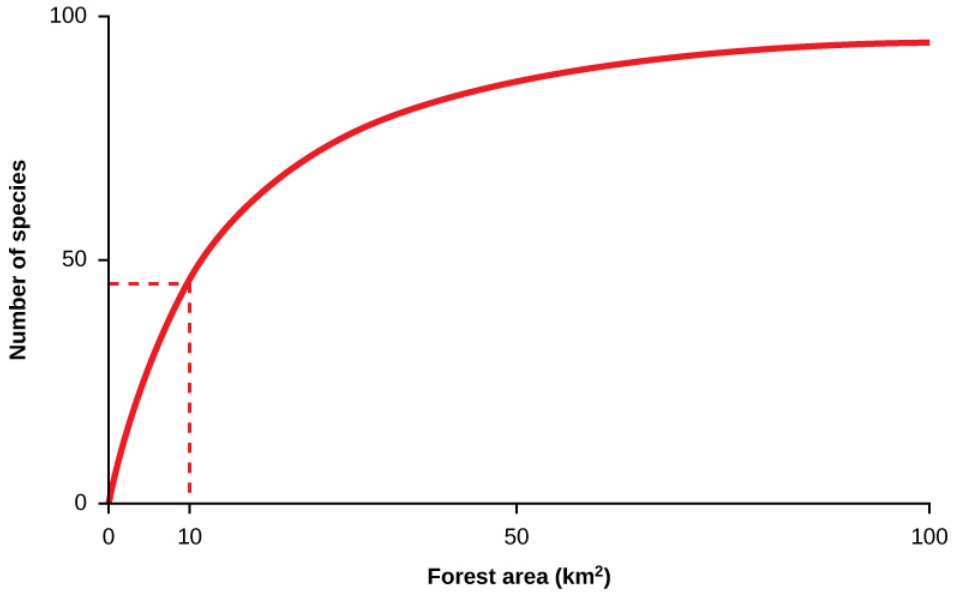


Figure $Page 7.5.3$. A typical species-area curve shows the cumulative number of species found as more and more area is sampled. The curve has also been interpreted to show the effect on species numbers of destroying habitat; a reduction in habitat of 90 percent from 100 km^2 to 10 km^2 reduces the number of species supported by about 50 percent.

A second approach to estimating present-time extinction rates is to correlate species loss with habitat loss, and it is based on measuring forest-area loss and understanding species–area relationships. The species-area relationship is the rate at which new species are seen when the area surveyed is increased (Figure $Page 7.5.3$). Likewise, if the habitat area is reduced, the number of species seen will also decline. This kind of relationship is also seen in the relationship between an island's area and the number of species present on the island: as one increases, so does the other, though not in a straight line. Estimates of extinction rates based on habitat loss and species–area relationships have suggested that with about 90 percent of habitat loss an expected 50 percent of species would become extinct. Figure $Page 7.5.3$ shows that reducing forest area from 100 km^2 to 10 km^2, a decline of 90 percent, reduces the number of species by about 50 percent. Species–area estimates have led to estimates of present-day species extinction rates of about 1000 E/MSY and higher.

Conservation of Biodiversity

The threats to biodiversity have been recognized for some time. Today, the main efforts to preserve biodiversity involve legislative approaches to regulate human and corporate behavior, setting aside protected areas, and habitat restoration.

Changing Human Behavior

Legislation has been enacted to protect species throughout the world. The legislation includes international treaties as well as national and state laws. The **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** treaty came into force in 1975. The treaty, and the national legislation that supports it, provides a legal framework for preventing "listed" species from being transported across nations' borders, thus protecting them from being caught or killed when the purpose involves international trade. The listed species that are protected by the treaty number some 33,000. The treaty is limited in its reach because it only deals with international movement of organisms or their parts. It is also limited by various countries' ability or willingness to enforce the treaty and supporting legislation. The illegal trade in organisms and their parts is probably a market in the hundreds of millions of dollars.

Within many countries there are laws that protect endangered species and that regulate hunting and fishing. In the United States, the **Endangered Species Act** (ESA) was enacted in 1973. When an at-risk species is listed by the Act, the U.S. Fish & Wildlife Service is required by law to develop a management plan to protect the species and bring it back to sustainable numbers. The ESA, and others like it in other countries, is a useful tool, but it suffers because it is often difficult to get a species listed or to get an effective management plan in place once a species is listed.

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The **Migratory Bird Treaty Act** (MBTA) is an agreement between the United States and Canada that was signed into law in 1918 in response to declines in North American bird species caused by hunting. The Act now lists over 800 protected species. It makes it illegal to disturb or kill the protected species or distribute their parts (much of the hunting of birds in the past was for their feathers). Examples of protected species include northern cardinals, the red-tailed hawk, and the American black vulture.

Global warming is expected to be a major driver of biodiversity loss. Many governments are concerned about the effects of anthropogenic global warming, primarily on their economies and food resources. Because greenhouse gas emissions do not respect national boundaries, the effort to curb them is international. The international response to global warming has been mixed. The **Kyoto Protocol**, an international agreement that came out of the United Nations Framework Convention on Climate Change that committed countries to reducing greenhouse gas emissions by 2012, was ratified by some countries, but spurned by others. Two countries that were especially important in terms of their potential impact that did not ratify the Kyoto protocol were the United States and China. Some goals for reduction in greenhouse gasses were met and exceeded by individual countries, but, worldwide, the effort to limit greenhouse gas production is not succeeding. A renegotiated 2016 treaty, called the **Paris Agreement**, once again brought nations together to take meaningful action on climate change. But like before, some nations are reluctant to participate. The newly-elected President Trump has indicated that he will withdraw the United States' support of the agreement.

Conservation in Preserves



Figure $Page 7.5.4$. National parks, such as Grand Teton National Park in Wyoming, help conserve biodiversity. (credit: Don DeBold)

Establishment of wildlife and ecosystem preserves is one of the key tools in conservation efforts (Figure $Page 7.5.4$). A **preserve** is an area of land set aside with varying degrees of protection for the organisms that exist within the boundaries of the preserve. In 2003, the IUCN World Parks Congress estimated that 11.5 percent of Earth's land surface was covered by preserves of various kinds. This area is large but only represents 9 out of 14 recognized major biomes and research has shown that 12 percent of all species live outside preserves.

A **biodiversity hotspot** is a conservation concept developed by Norman Myers in 1988. Hotspots are geographical areas that contain high numbers of endemic species. The purpose of the concept was to identify important locations on the planet for conservation efforts, a kind of conservation triage. By protecting hotspots, governments are able to protect a larger number of species. The original criteria for a hotspot included the presence of 1500 or more species of endemic plants and 70 percent of the area disturbed by human activity. There are now 34 biodiversity hotspots (Figure $Page 7.5.5$) that contain large numbers of endemic species, which include half of Earth's endemic plants.

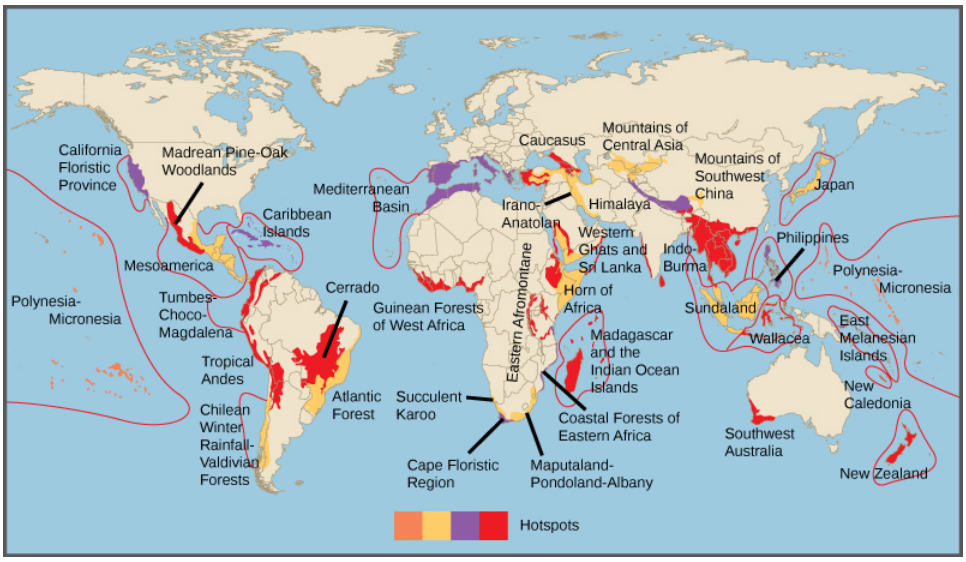


Figure $Page 7.5.5$. Conservation International has identified 34 biodiversity hotspots. Although these cover only 2.3 percent of the Earth's surface, 42 percent of the terrestrial vertebrate species and 50 percent of the world's plants are endemic to those hotspots.

There has been extensive research into optimal preserve designs for maintaining biodiversity. The fundamental principles behind much of the research have come from the seminal theoretical work of Robert H. MacArthur and Edward O. Wilson published in 1967 on island biogeography.[1]This work sought to understand the factors affecting biodiversity on islands. Conservation preserves can be seen as "islands" of habitat within "an ocean" of non-habitat. In general, large preserves are better because they support more species, including species with large home ranges; they have more core area of optimal habitat for individual species; they have more niches to support more species; and they attract more species because they can be found and reached more easily. One large preserve is better than the same area of several smaller preserves because there is more core habitat unaffected by less hospitable ecosystems outside the preserve boundary. For this same reason, preserves in the shape of a square or circle will be better than a preserve with many thin "arms." If preserves must be smaller, then providing **wildlife corridors** (narrow strips of protected land) between two preserves is important so that species and their genes can move between them. All of these factors are taken into consideration when planning the nature of a preserve before the land is set aside.

In addition to the physical specifications of a preserve, there are a variety of regulations related to the use of a preserve. These can include anything from timber extraction, mineral extraction, regulated hunting, human habitation, and nondestructive human recreation. Many of the decisions to include these other uses are made based on political pressures rather than conservation considerations. On the other hand, in some cases, wildlife protection policies have been so strict that subsistence-living indigenous populations have been forced from ancestral lands that fell within a preserve. In other cases, even if a preserve is designed to protect wildlife, if the protections are not or cannot be enforced, the preserve status will have little meaning in the face of illegal poaching and timber extraction. This is a widespread problem with preserves in the tropics.

Climate change will create inevitable problems with the location of preserves as the species within them migrate to higher latitudes as the habitat of the preserve becomes less favorable. Planning for the effects of global warming on future preserves, or adding new preserves to accommodate the changes expected from global warming is in progress, but will only be as effective as the accuracy of the predictions of the effects of global warming on future habitats.

Finally, an argument can be made that conservation preserves reinforce the cultural perception that humans are separate from nature, can exist outside of it, and can only operate in ways that do damage to biodiversity. Creating preserves reduces the pressure on human activities outside the preserves to be sustainable and non-damaging to biodiversity. Ultimately, the political, economic, and human demographic pressures will degrade and reduce the size of conservation preserves if the activities outside them are not altered to be less damaging to biodiversity.

Habitat Restoration

Habitat restoration is the process of bringing an area back to its natural state, before it was impacted through destructive human activities. It holds considerable promise as a mechanism for maintaining or restoring biodiversity. Reintroducing wolves, a top

predator, to Yellowstone National Park in 1995 led to dramatic changes in the ecosystem that increased biodiversity. The wolves (Figure $Page7.5.6$) function to suppress elk and coyote populations and provide more abundant resources to the detritivores. Reducing elk populations has allowed revegetation of riparian (the areas along the banks of a stream or river) areas, which has increased the diversity of species in that habitat. Reduction of coyote populations by wolves has increased the prey species previously suppressed by coyotes. In this habitat, the wolf is a **keystone species**, meaning a species that is instrumental in maintaining diversity within an ecosystem. Removing a keystone species from an ecological community causes a collapse in diversity. The results from the Yellowstone experiment suggest that restoring a keystone species effectively can have the effect of restoring biodiversity in the community. Ecologists have argued for the identification of keystone species where possible and for focusing protection efforts on these species. It makes sense to return the keystone species to the ecosystems where they have been removed.



Figure $Page7.5.6$. This photograph shows the Gibbon wolf pack in Yellowstone National Park, March 1, 2007. Wolves have been identified as a keystone species. (credit: Doug Smith, NPS)

Other large-scale restoration experiments underway involve dam removal. In the United States, since the mid-1980s, many aging dams are being considered for removal rather than replacement because of shifting beliefs about the ecological value of free-flowing rivers. The measured benefits of dam removal include restoration of naturally fluctuating water levels (often the purpose of dams is to reduce variation in river flows), which leads to increased fish diversity and improved water quality. In the Pacific Northwest of the United States, dam removal projects are expected to increase populations of salmon, which is considered a keystone species because it transports nutrients to inland ecosystems during its annual spawning migrations. In other regions, such as the Atlantic coast, dam removal has allowed the return of other spawning anadromous fish species (species that are born in fresh water, live most of their lives in salt water, and return to fresh water to spawn). Some of the largest dam removal projects have yet to occur or have happened too recently for the consequences to be measured, such as Elwha Dam on the Olympic Peninsula of Washington State. The large-scale ecological experiments that these removal projects constitute will provide valuable data for other dam projects slated either for removal or construction.

The Role of Zoos and Captive Breeding

Zoos have sought to play a role in conservation efforts both through captive breeding programs and education (Figure $Page7.5.7$). The transformation of the missions of zoos from collection and exhibition facilities to organizations that are dedicated to conservation is ongoing. In general, it has been recognized that, except in some specific targeted cases, captive breeding programs for endangered species are inefficient and often prone to failure when the species are reintroduced to the wild. Zoo facilities are far too limited to contemplate captive breeding programs for the numbers of species that are now at risk. Education, on the other hand, is a potential positive impact of zoos on conservation efforts, particularly given the global trend to urbanization and the consequent reduction in contacts between people and wildlife. A number of studies have been performed to look at the effectiveness of zoos on people's attitudes and actions regarding conservation and at present, the results tend to be mixed.


Figure $Page 7.5.7$. Zoos and captive breeding programs help preserve many endangered species, such as this golden lion tamarin. (credit: Garrett Ziegler)

Suggested Supplemental Reading:

Paterniti. 2017. Should we Kill Animals to Save Them? *National Geographic*. October.

This article in National Geographic takes a closer look at whether or not sport hunting benefits wildlife conservation.

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Page 7.6: Chapter Resources

Summary

Biodiversity exists at multiple levels of organization, and is measured in different ways depending on the goals of those taking the measurements. These include numbers of species, genetic diversity, chemical diversity, and ecosystem diversity. Humans use many compounds that were first discovered or derived from living organisms as medicines: secondary plant compounds, animal toxins, and antibiotics produced by bacteria and fungi. Ecosystems provide ecosystem services that support human agriculture: pollination, nutrient cycling, pest control, and soil development and maintenance. Loss of biodiversity threatens these ecosystem services and risks making food production more expensive or impossible. The core threats to biodiversity are human population growth and unsustainable resource use. Climate change is predicted to be a significant cause of extinction in the coming century. Exotic species have been the cause of a number of extinctions and are especially damaging to islands and lakes. International treaties such as CITES regulate the transportation of endangered species across international borders. In the United States, the Endangered Species Act protects listed species but is hampered by procedural difficulties and a focus on individual species. The Migratory Bird Act is an agreement between Canada and the United States to protect migratory birds. Presently, 11 percent of Earth's land surface is protected in some way. Habitat restoration has the potential to restore ecosystems to previous biodiversity levels before species become extinct. Examples of restoration include reintroduction of keystone species and removal of dams on rivers.

Review Questions

1. Bacteria that feed upon decaying organic matter in the soil would best be described as which one of the following?
   A. Eukaryotic
   B. Autotrophic
   C. Fungi
   D. Cyanobacteria
   E. Heterotrophic
2. As Darwin recognized, populations evolve through natural selection when which of the following condition(s) are met?
   A. Variation of traits among individuals
   B. Competition for limited resources
   C. More offspring are produced than can survive
   D. All of the above
3. You are the world's foremost expert on lizards. You have traveled the world extensively and have found that a particular species of lizard is found only in one desert near of the Chilean Andes. Which of following terms, with regard to its distribution, can be definitively applied to this species?
   A. Endangered
   B. Prokaryotic
   C. Endemic
   D. Disbursed
   E. Clustered
4. Which one of the following is not a major cause of biodiversity loss?
   A. Habitat loss
   B. Climate change
   C. Invasive Species
   D. Zoonotic diseases
   E. Overharvesting
5. Which one of the following statements is false?
   A. There have been five mass extinctions preserved in the fossil record
   B. Some bacteria are autotrophs
   C. Current rates of extinction are higher than background extinction rates
   D. Speciation is the process of creating new species

E. All living things can be classified into one of four taxonomic domains

6. During the middle of the 19th century, which scientist independently derived and proposed a theory of evolution that was similar to Darwin's?
   A. Gregor Mendel
   B. Alfred Wallace
   C. Isaac Newton
   D. Rachel Carson
   E. Niels Bohr
7. The study of the distribution of the world's species both in the past and in the present is known by what term?
   A. Geology
   B. Biogeography
   C. Biodiversity
   D. Biogeomorphology
   E. Ecological Succession
8. Which one of the following would be described as anthropogenic?
   A. Water backing up behind a beaver dam
   B. The dinosaurs going extinct
   C. Logging a forest
   D. A mudslide burying a stream
   E. A volcanic eruption
9. By definition, what are you most likely to find in a biodiversity hotspot?
   A. A large abundance of endangered species
   B. A large number of endemic species
   C. Mostly eukaryotic species
   D. Extremophiles
   E. Heat-loving microbes
10. You are working as a biologist for a team surveying biodiversity in the Amazon rainforest. You find a non-motile organism that grows in the soil, has eukaryotic cells, and is heterotrophic. Which one of the following could potentially describe this species?
    A. Fungus
    B. Animal
    C. Bacteria
    D. Plant
    E. Archaea

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

8: Environmental Hazards and Human Health

Learning Outcomes

- Define environmental health
- Categorize environmental health risks
- Explain the concept of emerging diseases
- Summarize the principles of environmental toxicology
- Classify environmental contaminants

Page 8.1: The Impacts of Environmental Conditions

Page 8.2: Environmental Health

Page 8.3: Environmental Toxicology

Page 8.4: Bioremediation

Page 8.5: Case Study - The Love Canal Disaster

Page 8.S: Environmental Hazards and Human Health (Summary)

Thumbnail image - Bayee Waqo (12) was named after her grandmother Bayee Chumee (82). When her son and his wife both died of AIDS, Chumee took on the care of their daughter who was just two years old. Some years later, after repeated illness, the young girl was diagnosed HIV positive, and she has been on treatment since. At 82, Chumee is getting too weak for all the household chores, so her granddaughter helps by collecting firewood, fetching water, making coffee and baking bread.

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Page 8.1: The Impacts of Environmental Conditions

Our industrialized society dumps huge amounts of pollutants and toxic wastes into the earth's biosphere without fully considering the consequences. Such actions seriously degrade the health of the earth's ecosystems, and this degradation ultimately affects the health and well-being of human populations.

For most of human history, **biological agents** were the most significant factor in health. These included pathogenic (disease causing) organisms such as bacteria, viruses, protozoa, and internal parasites. In modern times, cardiovascular diseases, cancer, and accidents are the leading killers in most parts of the world. However, infectious diseases still cause about 22 million deaths a year, mostly in undeveloped countries. These diseases include: tuberculosis, malaria, pneumonia, influenza, whooping cough, dysentery and Acquired Immune Deficiency Syndrome (AIDS). Most of those affected are children. Malnutrition, unclean water, poor sanitary conditions and lack of proper medical care all play roles in these deaths. Compounding the problems of infectious diseases are factors such as drug-resistant pathogens, insecticide resistant carriers, and overpopulation. Overuse of antibiotics have allowed pathogens to develop a resistance to drugs. For example, tuberculosis (TB) was nearly eliminated in most parts of the world, but drug-resistant strains have now reversed that trend. Another example is malaria. The insecticide DDT (a chemical called dichlorodiphenyltrichloroethane) was widely used to control malaria-carrying mosquito populations in tropical regions. However, after many years the mosquitoes developed a natural resistance to DDT and again spread the disease widely. Anti-malarial medicines were also over-prescribed, which allowed the malaria pathogen to become drug-resistant.

Chemical agents also have significant effects on human health. Toxic heavy metals, dioxins, pesticides, and endocrine disrupters are examples of these chemical agents. Heavy metals (e.g., mercury, lead, & cadmium) are typically produced as by-products of mining and manufacturing processes. All of them biomagnify (become more concentrated in species with increasing food chain level). For example, mercury from polluted water can accumulate in swordfish to levels toxic to humans. When toxic heavy metals get into the body, they accumulate in tissues and may eventually cause sickness or death. Studies show that people with above-average lead levels in their bones have an increased risk of developing attention deficit disorder and aggressive behavior. Lead can also damage brain cells and affect muscular coordination.

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ENVIRONMENTAL PERSISTENCE OF DDT



Figure $Page 8.1.1$. DDT was a commonly-used pesticide. *"This work" by OpenStax is licensed under CC BY 4.0.*

The pesticide DDT was widely used for decades. It was seen as an ideal pesticide because it is inexpensive and breaks down slowly in the environment. Unfortunately, the latter characteristic allows this chemical agent to biomagnify through the food chain. Populations of bird species at the top of the food chain, e.g., eagles and pelicans, are greatly affected by DDT in the environment. When these birds have sufficient levels of DDT, the shells of their eggs are so thin that they break, making reproduction impossible. After DDT was banned in the United States in 1972, affected bird populations made noticeable recoveries, including the iconic bald eagle.

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Page 8.2: Environmental Health

Environmental health is concerned with preventing disease, death and disability by reducing exposure to adverse environmental conditions and promoting behavioral change. It focuses on the direct and indirect causes of diseases and injuries, and taps resources inside and outside the health care system to help improve health outcomes.

Table 1. Typical Environmental Health Issues: Determinants and Health Consequences.

Underlying Determinants	Possible Adverse Health and Safety Consequences
Inadequate water (quantity and quality), sanitation (wastewater and excreta removal) and solid waste disposal, improper hygiene (hand washing)	Diarrheas and vector-related diseases, eg, malaria, schistosomiasis, dengue
Improper water resource management (urban and rural), including poor drainage	Vector-related diseases, eg, malaria, schistosomiasis
Crowded housing and poor ventilation of smoke	Acute and chronic respiratory diseases, including lung cancer (from coal and tobacco smoke inhalation)
Exposures to vehicular and industrial air pollution	Respiratory diseases, some cancers, and loss of IQ in children
Population movement and encroachment and construction, which affect feeding and breeding grounds of vectors, such as mosquitoes	Vector-related diseases, eg, malaria, schistosomiasis, and dengue fever, may also help spread other infectious diseases eg HIV/AIDS, Ebola fever
Exposure to naturally occurring toxic substances	Poisoning from, eg, arsenic, manganese, and fluorides
Natural resource degradation, eg, mudslides, poor drainage, erosion	Injury and death from mudslides and flooding
Climate change, partly from combustion of greenhouse gases in transportation, industry and poor energy conservation in housing, fuel, commerce, industry	Injury/death from: extreme heat/cold, storms, floods, fires. Indirect effects: spread of vector-borne diseases, aggravation of respiratory diseases, population dislocation, water pollution from sea level rise, etc.
Ozone depletion from industrial and commercial activity	Skin cancer, cataracts. Indirect effects: compromised food production, etc.

Poverty, Health and Environment

Environmental health risks can be grouped into two broad categories. **Traditional hazards** are related to poverty and the lack of development and mostly affect developing countries and poor people. Their impact exceeds that of modern health hazards by 10 times in Africa, 5 times in Asian countries (except for China), and 2.5 times in Latin America and Middle East (Figure *Page*8.2.1). Water-related diseases caused by inadequate water supply and sanitation impose an especially large health burden in Africa, Asia, and the Pacific region. In India alone, over 700,000 children under 5 die annually from diarrhea. In Africa, malaria causes about 500,000 deaths annually. More than half of the world's households use unprocessed *solid fuels*, particularly biomass (crop residues, wood, and dung) for cooking and heating in inefficient stoves without proper ventilation, exposing people—mainly poor women and children—to high levels of indoor air pollution(IAP). IAP causes about 2 million deaths in each year.

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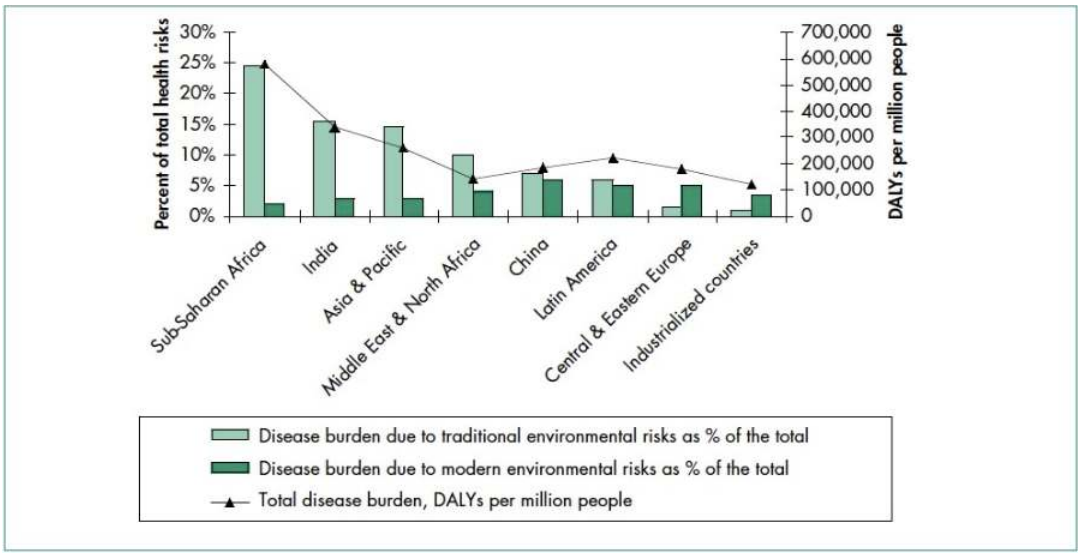


Figure $Page 8.2.1$. Traditional environmental health hazards prevail in developing countries but modern risks are also significant.

Modern hazards, caused by technological development, prevail in industrialized countries where exposure to traditional hazards is low. The contribution of modern environmental risks to the disease burden in most developing countries is similar to – and in quite a few countries, greater than – that in rich countries. Urban air pollution, for example, is highest in parts of China, India and some cities in Asia and Latin America. Poor people increasingly experience a "**double burden**" of traditional and modern environmental health risks. Their total burden of illness and death from all causes per million people is about twice that in rich countries, and the disease burden from environmental risks is 10 times greater.

Environmental Health and Child Survival



Figure $Page 8.2.2$. Malnourished children in Niger, during the 2005 famine.

Worldwide, the top killers of children under five are acute respiratory infections (from indoor air pollution); diarrheal diseases (mostly from poor water, sanitation, and hygiene); and infectious diseases such as malaria. Children are especially susceptible to environmental factors that put them at risk of developing illness early in life. **Malnutrition** (the condition that occurs when body does not get enough nutrients) is an important contributor to child mortality—malnutrition and environmental infections are inextricably linked. The World Health Organization (WHO) recently concluded that about 50% of the consequences of malnutrition are in fact caused by inadequate water and sanitation provision and poor hygienic practices.

Poor Water and Sanitation Access

With 1.1 billion people lacking access to safe drinking water and 2.6 billion without adequate sanitation, the magnitude of the water and sanitation problem remains significant. Each year contaminated water and poor sanitation contribute to 5.4 billion cases of

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diarrhea worldwide and 1.6 million deaths, mostly among children under the age of five. Intestinal worms, which thrive in poor sanitary conditions, infect close to 90 percent of children in the developing world and, depending on the severity of the infection may lead to malnutrition, anemia, or stunted growth. About 6 million people are blind from trachoma, a disease caused by the lack of clean water combined with poor hygiene practices.

Indoor Air Pollution

Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7% of global burden of disease. It is estimated that half of the world's population, mainly in developing countries, uses solid fuels (biomass and coal) for household cooking and space heating. Cooking and heating with such solid fuels on open fires or stoves without chimneys lead to indoor air pollution and subsequently, respiratory infections. Exposure to these health-damaging pollutants is particularly high among women and children in developing countries, who spend the most time inside the household. As many as half of the deaths attributable to indoor use of solid fuel are of children under the age of five.

Malaria

Approximately 40% of the world's people—mostly those living in the world's poorest countries—are at risk from malaria. **Malaria** is an infectious disease spread by mosquitoes but caused by a single-celled parasite called *Plasmodium*. Every year, more than 200 million people become infected with malaria and about 430,000 die, with most cases and deaths found in Sub-Saharan Africa. However, Asia, Latin America, the Middle East, and parts of Europe are also affected. Pregnant women are especially at high risk of malaria. Non-immune pregnant women risk both acute and severe clinical disease, resulting in fetal loss in up to 60% of such women and maternal deaths in more than 10%, including a 50% mortality rate for those with severe disease. Semi-immune pregnant women with malaria infection risk severe anemia and impaired fetal growth, even if they show no signs of acute clinical disease. An estimated 10,000 women and 200,000 infants die annually as a result of malaria infection during pregnancy.

Emerging Diseases

Emerging and re-emerging diseases have been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts. Examples include Ebola virus, West Nile virus, Zika virus, sudden acute respiratory syndrome (SARS), H1N1 influenza; swine and avian influenza (swine, bird flu), HIV, and a variety of other viral, bacterial, and protozoal diseases.

A variety of environmental factors may contribute to re-emergence of a particular disease, including temperature, moisture, human food or animal feed sources, etc. Disease re-emergence may be caused by the coincidence of several of these environmental and/or social factors to allow optimal conditions for transmission of the disease.

Ebola, previously known as Ebola hemorrhagic fever, is a rare and deadly disease caused by infection with one of the Ebola virus strains. Ebola can cause disease in humans and nonhuman primates. The 2014 Ebola epidemic is the largest in history (with over 28,000 cases and 11,302 deaths), affecting multiple countries in West Africa. There were a small number of cases reported in Nigeria and Mali and a single case reported in Senegal; however, these cases were contained, with no further spread in these countries.

The **HIV/AIDS** epidemic has spread with ferocious speed. Virtually unknown 20 years ago, HIV has infected more than 60 million people worldwide. Each day, approximately 14,000 new infections occur, more than half of them among young people below age 25. Over 95 percent of PLWHA (People Living With HIV/AIDS) are in low- and middle- income countries. More than 20 million have died from AIDS, over 3 million in 2002 alone. AIDS is now the leading cause of death in Sub-Saharan Africa and the fourth-biggest killer globally. The epidemic has cut life expectancy by more than 10 years in several nations.

It seems likely that a wide variety of infectious diseases have affected human populations for thousands of years emerging when the environmental, host, and agent conditions were favorable. Expanding human populations have increased the potential for transmission of infectious disease as a result of close human proximity and increased likelihood for humans to be in "the wrong place at the right time" for disease to occur (eg, natural disasters or political conflicts). Global travel increases the potential for a carrier of disease to transmit infection thousands of miles away in just a few hours, as evidenced by WHO precautions concerning international travel and health.

Antibiotic Resistance

Antibiotics and similar drugs, together called antimicrobial agents, have been used for the last 70 years to treat patients who have infectious diseases. Since the 1940s, these drugs have greatly reduced illness and death from infectious diseases. However, these drugs have been used so widely and for so long that the infectious organisms the antibiotics are designed to kill have adapted to them, making the drugs less effective. **Antibiotic resistance** occurs when bacteria change in a way that reduces the effectiveness of drugs, chemicals, or other agents designed to cure or prevent infections. This is caused by the process of evolution through natural selection (Figure $Page 8.2.3$). The antibiotic-resistant bacteria survive and continue to multiply, causing more harm.

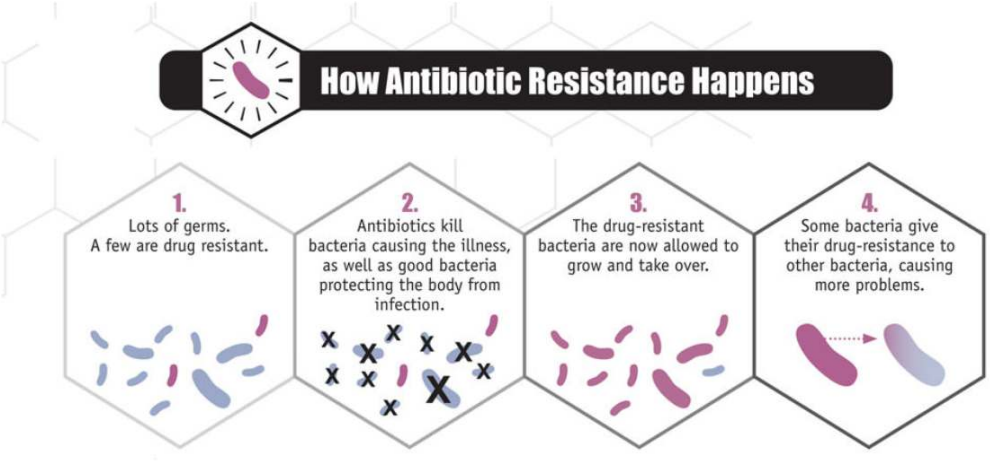


Figure $Page 8.2.3$. Antibiotic resistance is of increasing concern to medical professionals.

New forms of antibiotic resistance can cross international boundaries and spread between continents with ease. Many forms of resistance spread with remarkable speed. Each year in the United States, at least 2 million people acquire serious infections with bacteria that are resistant to one or more of the antibiotics designed to treat those infections. At least 23,000 people die each year in the US as a direct result of these antibiotic-resistant infections. Many more die from other conditions that were complicated by an antibiotic-resistant infection. The use of antibiotics is the single most important factor leading to antibiotic resistance around the world.



Video $Page 8.2.1$. Click here for a video link to an experiment done at Harvard Medical school, where they show bacteria adapting very quickly to apparently deadly conditions.

Antibiotics are among the most commonly prescribed drugs used in human medicine, but up to 50% of all the antibiotics prescribed for people are not needed or are not optimally effective as prescribed.

During recent years, there has been growing concern over methicillin-resistant *Staphylococcus aureus* (**MRSA),** a bacterium that is resistant to many antibiotics. In the community, most MRSA infections are skin infections. In medical facilities, MRSA causes life-threatening bloodstream infections, pneumonia and surgical site infections.

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Suggested Supplementary Reading:

Koch, B.J. et al. 2017. Food-animal production and the spread of antibiotic resistance: the role of ecology. *Frontiers in Ecology and the Environment* (15)6: 309-318.

> *Notable Excerpts:*
>
> *"Antibiotic use in food animals is correlated with antibiotic resistance among bacteria affecting human populations." p. 311*
>
> *"Microbial genes encoding antibiotic resistance have moved between the food-animal and human health sectors, resulting in illnesses that could not be treated by antibiotics." p. 312*

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Page 8.3: Environmental Toxicology

Environmental toxicology is the scientific study of the health effects associated with exposure to toxic chemicals (Table 1) occurring in the natural, work, and living environments. The term also describes the management of environmental toxins and toxicity, and the development of protections for humans and the environment.

2013 RANK	NAME
1	ARSENIC
2	LEAD
3	MERCURY
4	VINYL CHLORIDE
5	POLYCHLORINATED BIPHENYLS
6	BENZENE
7	CADMIUM
8	BENZO(A)PYRENE
9	POLYCYCLIC AROMATIC HYDROCARBONS
10	BENZO(B)FLUORANTHENE
11	CHLOROFORM
12	AROCLOR 1260
13	DDT, P,P'-
14	AROCLOR 1254
15	DIBENZO(A,H)ANTHRACENE
16	TRICHLOROETHYLENE
17	CHROMIUM, HEXAVALENT
18	DIELDRIN
19	PHOSPHORUS, WHITE
20	HEXACHLOROBUTADIENE

Routes of Exposure to Chemicals

In order to cause health problems, chemicals must enter your body. There are three main "routes of exposure," or ways a chemical can get into your body.

- Breathing (inhalation): Breathing in chemical gases, mists, or dusts that are in the air.
- Skin or eye contact: Getting chemicals on the skin, or in the eyes. They can damage the skin, or be absorbed through the skin into the bloodstream.
- Swallowing (ingestion): This can happen when chemicals have spilled or settled onto food, beverages, cigarettes, beards, or hands.

Once chemicals have entered your body, some can move into your bloodstream and reach internal "target" organs, such as the lungs, liver, kidneys, or nervous system.

What Forms do Chemicals Take?

Chemical substances can take a variety of forms. They can be in the form of solids, liquids, dusts, vapors, gases, fibers, mists and fumes. The form a substance is in has a lot to do with how it gets into your body and what harm it can cause. A chemical can also change forms. For example, liquid solvents can evaporate and give off vapors that you can inhale. Sometimes chemicals are in a form that can't be seen or smelled, so they can't be easily detected.

What Health Effects Can Chemicals Cause?

An **acute effect** of a contaminant (The term "**contaminant**" means hazardous substances, pollutants, pollution, and chemicals) is one that occurs rapidly after exposure to a large amount of that substance. A chronic effect of a contaminant results from exposure to small amounts of a substance over a long period of time. In such a case, the effect may not be immediately obvious. **Chronic effect** are difficult to measure, as the effects may not be seen for years. Long-term exposure to cigarette smoking, low level radiation exposure, and moderate alcohol use are all thought to produce chronic effects.

For centuries, scientists have known that just about any substance is toxic in sufficient quantities. For example, small amounts of selenium are required by living organisms for proper functioning, but large amounts may cause cancer. The effect of a certain chemical on an individual depends on the dose (amount) of the chemical. This relationship is often illustrated by a dose-response curve which shows the relationship between dose and the response of the individual. **Lethal doses** in humans have been determined for many substances from information gathered from records of homicides, accidental poisonings, and testing on animals.

A dose that is lethal to 50% of a population of test animals is called the **lethal dose-50%** or **LD-50**. Determination of the LD-50 is required for new synthetic chemicals in order to give a measure of their toxicity. A dose that causes 50% of a population to exhibit any significant response (e.g., hair loss, stunted development) is referred to as the **effective dose-50%** or **ED-50**. Some toxins have a threshold amount below which there is no apparent effect on the exposed population.

Environmental Contaminants

The contamination of the air, water, or soil with potentially harmful substances can affect any person or community. Contaminants (Table 2) are often chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources. Sometimes harmful environmental contaminants occur biologically, such as mold or a toxic algae bloom.

Table 2. Classification of Environmental Contaminants

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Contaminant	Definition
Carcinogen	An agent which may produce cancer (uncontrolled cell growth), either by itself or in conjunction with another substance. Examples include formaldehyde, asbestos, radon, vinyl chloride, and tobacco.
Teratogen	A substance which can cause physical defects in a developing embryo. Examples include alcohol and cigarette smoke.
Mutagen	A material that induces genetic changes (mutations) in the DNA. Examples include radioactive substances, x-rays and ultraviolet radiation.
Neurotoxicant	A substance that can cause an adverse effect on the chemistry, structure or function of the nervous system. Examples include lead and mercury.
Endocrine disruptor	A chemical that may interfere with the body's endocrine (hormonal) system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife. A wide range of substances, both natural and man-made, are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, arsenic, polychlorinated biphenyls (PCBs), DDT and other pesticides, and plasticizers such as bisphenol A (BPA).

An Overview of Some Common Contaminants

Arsenic is a naturally occurring element that is normally present throughout our environment in water, soil, dust, air, and food. Levels of arsenic can regionally vary due to farming and industrial activity as well as natural geological processes. The arsenic from farming and smelting tends to bind strongly to soil and is expected to remain near the surface of the land for hundreds of years as a long-term source of exposure. Wood that has been treated with chromated copper arsenate (CCA) is commonly found in decks and railing in existing homes and outdoor structures such as playground equipment. Some underground aquifers are located in rock or soil that has naturally high arsenic content.

Most arsenic gets into the body through ingestion of food or water. Arsenic in drinking water is a problem in many countries around the world, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the United States. Arsenic may also be found in foods, including rice and some fish, where it is present due to uptake from soil and water. It can also enter the body by breathing dust containing arsenic. Researchers are finding that arsenic, even at low levels, can interfere with the body's endocrine system. Arsenic is also a known human carcinogen associated with skin, lung, bladder, kidney, and liver cancer.

Mercury is a naturally occurring metal, a useful chemical in some products, and a potential health risk. Mercury exists in several forms; the types people are usually exposed to are methylmercury and elemental mercury. Elemental mercury at room temperature is a shiny, silver-white liquid which can produce a harmful odorless vapor. Methylmercury, an organic compound, can build up in the bodies of long-living, predatory fish. To keep mercury out of the fish we eat and the air we breathe, it's important to take mercury-containing products to a hazardous waste facility for disposal. Common products sold today that contain small amounts of mercury include fluorescent lights and button-cell batteries.

Although fish and shellfish have many nutritional benefits, consuming large quantities of fish increases a person's exposure to mercury. Pregnant women who eat fish high in mercury on a regular basis run the risk of permanently damaging their developing fetuses. Children born to these mothers may exhibit motor difficulties, sensory problems and cognitive deficits. Figure $Page8.3.1$ identifies the typical (average) amounts of mercury in commonly consumed commercial and sport-caught fish.

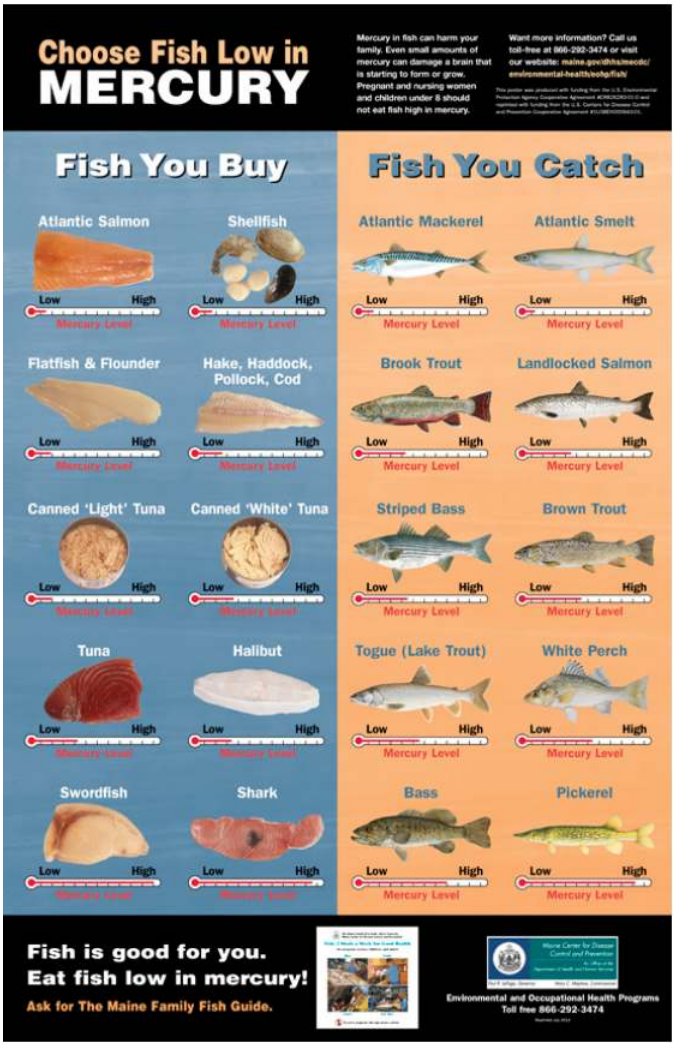


Figure $Page 8.3.1$. Mercury concentrations in fish can reach potentially dangerous levels (published by the *Maine Center for Disease Control & Prevention*).

Bisphenol A (BPA) is a chemical synthesized in large quantities for use primarily in the production of polycarbonate plastics and epoxy resins. Polycarbonate plastics have many applications including use in some food and drink packaging, e.g., water and infant bottles, compact discs, impact-resistant safety equipment, and medical devices. Epoxy resins are used as lacquers to coat metal products such as food cans, bottle tops, and water supply pipes. Some dental sealants and composites may also contribute to BPA exposure. The primary source of exposure to BPA for most people is through the diet. Bisphenol A can leach into food from the protective internal epoxy resin coatings of canned foods and from consumer products such as polycarbonate tableware, food storage containers, water bottles, and baby bottles. The degree to which BPA leaches from polycarbonate bottles into liquid may depend more on the temperature of the liquid or bottle, than the age of the container. BPA can also be found in breast milk.

What can I do to prevent exposure to BPA?

Some animal studies suggest that infants and children may be the most vulnerable to the effects of BPA. Parents and caregivers, can make the personal choice to reduce exposures of their infants and children to BPA:

- Don’t microwave polycarbonate plastic food containers. Polycarbonate is strong and durable, but over time it may break down from over use at high temperatures.
- Plastic containers have recycle codes on the bottom. Some, but not all, plastics that are marked with recycle codes 3 or 7 may be made with BPA.
- Reduce your use of canned foods.
- When possible, opt for glass, porcelain or stainless steel containers, particularly for hot food or liquids.
- Use baby bottles that are BPA free.

Phthalates are a group of synthetic chemicals used to soften and increase the flexibility of plastic and vinyl. Polyvinyl chloride is made softer and more flexible by the addition of phthalates. Phthalates are used in hundreds of consumer products. Phthalates are used in cosmetics and personal care products, including perfume, hair spray, soap, shampoo, nail polish, and skin moisturizers. They are used in consumer products such as flexible plastic and vinyl toys, shower curtains, wallpaper, vinyl miniblinds, food packaging, and plastic wrap. Exposure to low levels of phthalates may come from eating food packaged in plastic that contains phthalates or breathing dust in rooms with vinyl miniblinds, wallpaper, or recently installed flooring that contain phthalates. We can be exposed to phthalates by drinking water that contains phthalates. Phthalates are suspected to be endocrine disruptors.

Lead is a metal that occurs naturally in the rocks and soil of the earth's crust. It is also produced from burning fossil fuels such as coal, oil, gasoline, and natural gas; mining; and manufacturing. Lead has no distinctive taste or smell. The chemical symbol for elemental lead is Pb. Lead is used to produce batteries, pipes, roofing, scientific electronic equipment, military tracking systems, medical devices, and products to shield X-rays and nuclear radiation. It is used in ceramic glazes and crystal glassware. Because of health concerns, lead and lead compounds were banned from house paint in 1978; from solder used on water pipes in 1986; from gasoline in 1995; from solder used on food cans in 1996; and from tin-coated foil on wine bottles in 1996. The U.S. Food and Drug Administration has set a limit on the amount of lead that can be used in ceramics.

Lead and lead compounds are listed as "reasonably anticipated to be a human carcinogen". It can affect almost every organ and system in your body. It can be equally harmful if breathed or swallowed. The part of the body most sensitive to lead exposure is the central nervous system, especially in children, who are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead can develop brain damage that can cause convulsions and death; the child can also develop blood anemia, kidney damage, colic, and muscle weakness. Repeated low levels of exposure to lead can alter a child's normal mental and physical growth and result in learning or behavioral problems. Exposure to high levels of lead for pregnant women can cause miscarriage, premature births, and smaller babies. Repeated or chronic exposure can cause lead to accumulate in your body, leading to lead poisoning.



Figure $Page8.3.2$. Nail products are known to contain toxic chemicals, such as dibutyl phthalate (DBP), toluene, and formaldehyde.

Formaldehyde is a colorless, flammable gas or liquid that has a pungent, suffocating odor. It is a volatile organic compound, which is an organic compound that easily becomes a vapor or gas. It is also naturally produced in small, harmless amounts in the human body. The primary way we can be exposed to formaldehyde is by breathing air containing it. Releases of formaldehyde into the air occur from industries using or manufacturing formaldehyde, wood products (such as particle-board, plywood, and furniture), automobile exhaust, cigarette smoke, paints and varnishes, and carpets and permanent press fabrics. Nail polish, and commercially applied floor finish emit formaldehyde.

In general, indoor environments consistently have higher concentrations than outdoor environments, because many building materials, consumer products, and fabrics emit formaldehyde. Levels of formaldehyde measured in indoor air range from 0.02–4 parts per million (ppm). Formaldehyde levels in outdoor air range from 0.001 to 0.02 ppm in urban areas.

Radiation

Radiation is energy given off by atoms and is all around us. We are exposed to radiation every day from natural sources like soil, rocks, and the sun. We are also exposed to radiation from man-made sources like medical X-rays and smoke detectors. We're even exposed to low levels of radiation on cross-country flights, from watching television, and even from some construction materials. You cannot see, smell or taste radiation. Some types of radioactive materials are more dangerous than others. So it's important to carefully manage radiation and radioactive substances to protect health and the environment.

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Radon is a radioactive gas that is naturally-occurring, colorless, and odorless. It comes from the natural decay of uranium or thorium found in nearly all soils. It typically moves up through the ground and into the home through cracks in floors, walls and foundations. It can also be released from building materials or from well water. Radon breaks down quickly, giving off radioactive particles. Long-term exposure to these particles can lead to lung cancer. Radon is the leading cause of lung cancer among nonsmokers, according to the U.S. Environmental Protection Agency, and the second leading cause behind smoking.

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Page 8.4: Bioremediation

Bioremediation is a waste management technique that involves the use of organisms such as plants, bacteria, and fungi to remove or neutralize pollutants from a contaminated site. According to the United States EPA, bioremediation is a “treatment that uses naturally occurring organisms to break down hazardous substances into less toxic or non toxic substances”.

Bioremediation is widely used to treat human sewage and has also been used to remove agricultural chemicals (pesticides and fertilizers) that leach from soil into groundwater. Certain toxic metals, such as selenium and arsenic compounds, can also be removed from water by bioremediation. Mercury is an example of a toxic metal that can be removed from an environment by bioremediation. Mercury is an active ingredient of some pesticides and is also a byproduct of certain industries, such as battery production. Mercury is usually present in very low concentrations in natural environments but it is highly toxic because it accumulates in living tissues. Several species of bacteria can carry out the biotransformation of toxic mercury into nontoxic forms. These bacteria, such as *Pseudomonas aeruginosa*, can convert Hg^{2+} to Hg, which is less toxic to humans.

Probably one of the most useful and interesting examples of the use of prokaryotes for bioremediation purposes is the cleanup of oil spills. The importance of prokaryotes to petroleum bioremediation has been demonstrated in several oil spills in recent years, such as the Exxon Valdez spill in Alaska (1989) (Figure $Page8.4.1$), the Prestige oil spill in Spain (2002), the spill into the Mediterranean from a Lebanon power plant (2006,) and more recently, the BP oil spill in the Gulf of Mexico (2010). To clean up these spills, bioremediation is promoted by adding inorganic nutrients that help bacteria already present in the environment to grow. Hydrocarbon-degrading bacteria feed on the hydrocarbons in the oil droplet, breaking them into inorganic compounds. Some species, such as *Alcanivorax borkumensis*, produce surfactants that solubilize the oil, while other bacteria degrade the oil into carbon dioxide. In the case of oil spills in the ocean, ongoing, natural bioremediation tends to occur, inasmuch as there are oil-consuming bacteria in the ocean prior to the spill. Under ideal conditions, it has been reported that up to 80 percent of the nonvolatile components in oil can be degraded within 1 year of the spill. Researchers have genetically engineered other bacteria to consume petroleum products; indeed, the first patent application for a bioremediation application in the U.S. was for a genetically modified oil-eating bacterium.



(a) (b)

Figure $Page8.4.1$. (a) Cleaning up oil after the Valdez spill in Alaska, the workers hosed oil from beaches and then used a floating boom to corral the oil, which was finally skimmed from the water surface. Some species of bacteria are able to solubilize and degrade the oil. (b) One of the most catastrophic consequences of oil spills is the damage to fauna. (credit a: modification of work by NOAA; credit b: modification of work by GOLUBENKOV, NGO: Saving Taman)

There are a number of cost/efficiency advantages to bioremediation, which can be employed in areas that are inaccessible without excavation. For example, hydrocarbon spills (specifically, oil spills) or certain chlorinated solvents may contaminate groundwater, which can be easier to treat using bioremediation than more conventional approaches. This is typically much less expensive than excavation followed by disposal elsewhere, incineration, or other off-sitetreatment strategies. It also reduces or eliminates the need for “pump and treat”, a practice common at sites where hydrocarbons have contaminated clean groundwater. Using prokaryotes for bioremediation of hydrocarbons also has the advantage of breaking down contaminants at the molecular level, as opposed to simply chemically dispersing the contaminant.

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Page 8.5: Case Study - The Love Canal Disaster

One of the most famous and important examples of groundwater pollution in the U.S. is the **Love Canal tragedy** in Niagara Falls, New York. It is important because the pollution disaster at Love Canal, along with similar pollution calamities at that time (Times Beach, Missouri and Valley of Drums, Kentucky), helped to create **Superfund**, a federal program instituted in 1980 and designed to identify and clean up the worst of the hazardous chemical waste sites in the U.S.



Figure $Page 8.5.1$. Love Canal. Source: US Environmental Protection Agency

Love Canal is a neighborhood in Niagara Falls named after a large ditch (approximately 15 m wide, 3–12 m deep, and 1600 m long) that was dug in the 1890s for hydroelectric power. The ditch was abandoned before it actually generated any power and went mostly unused for decades, except for swimming by local residents. In the 1920s Niagara Falls began dumping urban waste into Love Canal, and in the 1940s the U.S. Army dumped waste from World War II there, including waste from the frantic effort to build a nuclear bomb. Hooker Chemical purchased the land in 1942 and lined it with clay. Then, the company put into Love Canal an estimated 21,000 tons of hazardous chemical waste, including the carcinogens benzene, dioxin, and PCBs in large metal barrels and covered them with more clay. In 1953, Hooker sold the land to the Niagara Falls school board for $1, and included a clause in the sales contract that both described the land use (filled with chemical waste) and absolved them from any future damage claims from the buried waste. The school board promptly built a public school on the site and sold the surrounding land for a housing project that built 200 or so homes along the canal banks and another 1,000 in the neighborhood (Figure $Page 8.5.1$). During construction, the canal's clay cap and walls were breached, damaging some of the metal barrels.

Eventually, the chemical waste seeped into people's basements, and the metal barrels worked their way to the surface. Trees and gardens began to die; bicycle tires and the rubber soles of children's shoes disintegrated in noxious puddles. From the 1950s to the late 1970s, residents repeatedly complained of strange odors and substances that surfaced in their yards. City officials investigated the area, but did not act to solve the problem. Local residents allegedly experienced major health problems including high rates of miscarriages, birth defects, and chromosome damage, but studies by the New York State Health Department disputed that. Finally, in 1978 President Carter declared a state of emergency at Love Canal, making it the first human-caused environmental problem to be designated that way. The Love Canal incident became a symbol of improperly stored chemical waste. Clean up of Love Canal, which was funded by Superfund and completely finished in 2004, involved removing contaminated soil, installing drainage pipes to capture contaminated groundwater for treatment, and covering it with clay and plastic. In 1995, Occidental Chemical (the modern name for Hooker Chemical) paid $102 million to Superfund for cleanup and $27 million to Federal Emergency Management Association for the relocation of more than 1,000 families. New York State paid $98 million to EPA and the US government paid $8 million for pollution by the Army. The total clean up cost was estimated to be $275 million.

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The Love Canal tragedy helped to create Superfund, which has analyzed tens of thousands of hazardous waste sites in the U.S. and cleaned up hundreds of the worst ones. Nevertheless, over 1,000 major hazardous waste sites with a significant risk to human health or the environment are still in the process of being cleaned.

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Page 8.S: Environmental Hazards and Human Health (Summary)

Summary

Environmental health is concerned with preventing disease, death and disability by reducing exposure to adverse environmental conditions and promoting behavioral change. It focuses on the direct and indirect causes of diseases and injuries, and taps resources inside and outside the health care system to help improve health outcomes. Environmental health risks can be grouped into two broad categories. Traditional hazards related to poverty and lack of development affect developing countries and poor people most. Modern hazards, caused by development that lacks environmental safeguards, such as urban (outdoor) air pollution and exposure to agro-industrial chemicals and waste, prevail in industrialized countries, where exposure to traditional hazards is low. Each year contaminated water and poor sanitation contribute to 5.4 billion cases of diarrhea worldwide and 1.6 million deaths, mostly among children under the age of five. Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7 percent of global burden of disease.

Emerging and reemerging diseases have been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts. Antibiotic resistance is a global problem. New forms of antibiotic resistance can cross international boundaries and spread between continents. Environmental toxicology is the scientific study of the health effects associated with exposure to toxic chemicals and systems occurring in the natural, work, and living environments; the management of environmental toxins and toxicity; and the development of protections for humans, animals, and plants. Environmental contaminants are chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources.

Review Questions

1. The pesticide DDT is an example of which one of the following?
   A. Biological agent
   B. Atomic agent
   C. Chemical agent
   D. Capricious agent
   E. Inorganic agent
2. From the perspective of human health, malnutrition is important because it…
   A. Causes the majority of birth defects
   B. Is the primary source of teratogens for most children
   C. is an important contributor to child mortality
   D. Is the second leading cause of death from emerging disease
   E. Increases the occurrence of infectious cancers
3. Antibiotic resistance in organisms is the result of what process?
   A. Differentiation
   B. Evolution
   C. Emergence
   D. Succession
   E. Fixation
4. Which one of the following is an example of an emerging disease?
   A. Malaria
   B. Ebola
   C. Cancer
   D. Heart disease
   E. Leukemia
5. “Effective dose – 50%” describes which one of the following?
   A. The dose that results in 50% mortality

B. The dose the results in 50% survival
C. The dose that is 50% less than the lethal dose
D. The dose that results in a significant response in 50% of subjects
E. The dose that is 50% more than the minimal dose

6. You are working as an environmental toxicologist for the government. Your results indicate that a particular chemical causes birth defects. Which one of the following best describes the effects of this chemical?

A. Teratogen
B. Carcinogen
C. Mutagen
D. Endocrine disruptor
E. Neurotoxicant

7. Which one of the following is most directly associated with radon?

A. Radiation
B. Endocrine disruption
C. Birth defects
D. Biological agents
E. Biomagnification

8. Which one of the following is an example of bioremediation?

A. Adding chemical dispersants following an oil spill
B. Growing large colonies of bacteria to produce antibiotic chemicals
C. Mimicking the processes of natural in a laboratory or industrial context
D. Removing invasive species that are overpopulating an ecosystem
E. Using plants to remove toxic metals from soils following a mining operation

9. Which one of the following is not a naturally-occurring element that may be hazardous to human health?

A. Lead
B. Radon
C. Phthalate
D. Mercury
E. Arsenic

10. Which one of the following is not true regarding the “Love Canal Disaster”?

A. It involved the improper storage of chemical waste
B. It was one of several incidents that led to the creation of the Superfund
C. A school was built on the contaminated site
D. Many homes had to be evacuated due to contamination from various biological agents
E. Many people living in the year reported serious health problems

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

9: Water Availability and Use

Learning Outcomes

- Understand how the water cycle operates
- Know the causes and effects of depletion in different water reservoirs
- Understand how we can work toward solving the water supply crisis
- Understand the major kinds of water pollutants and how they degrade water quality
- Understand how we can work toward solving the crisis involving water pollution

Page 9.1: Water Cycle and Fresh Water Supply

Page 9.2: Water Supply Problems and Solutions

Page 9.3: Water Pollution

Page 9.4: Water Treatment

Page 9.5: Case Study - The Aral Sea - Going, Going, Gone

Page 9.6: Chapter Resources

Thumbnail image - Great Lakes from Space. The Great Lakes hold 21% of the world's surface fresh water. Lakes are an important surface water resource.

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Page 9.1: Water Cycle and Fresh Water Supply

Water, air, and food are the most important natural resources to people. Humans can live only a few minutes without oxygen, less than a week without water, and about a month without food. Water also is essential for our oxygen and food supply. Plants breakdown water and use it to create oxygen during the process of photosynthesis.

Water is the most essential compound for all living things. Human babies are approximately 75% water and adults are 60% water. Our brain is about 85% water, blood and kidneys are 83% water, muscles are 76% water, and even bones are 22% water. We constantly lose water by perspiration; in temperate climates we should drink about 2 quarts of water per day and people in hot desert climates should drink up to 10 quarts of water per day. Loss of 15% of body-water usually causes death.

Earth is truly the Water Planet. The abundance of liquid water on Earth's surface distinguishes us from other bodies in the solar system. About 70% of Earth's surface is covered by oceans and approximately half of Earth's surface is obscured by clouds (also made of water) at any time. There is a very large volume of water on our planet, about 1.4 billion cubic kilometers (km3) (330 million cubic miles) or about 53 billion gallons per person on Earth. All of Earth's water could cover the United States to a depth of 145 km (90 mi). From a human perspective, the problem is that over 97% of it is seawater, which is too salty to drink or use for irrigation. The most commonly used water sources are rivers and lakes, which contain less than 0.01% of the world's water!

One of the most important environmental goals is to provide clean water to all people. Fortunately, water is a renewable resource and is difficult to destroy. Evaporation and precipitation combine to replenish our fresh water supply constantly; however, water availability is complicated by its uneven distribution over the Earth. Arid climate and densely populated areas have combined in many parts of the world to create water shortages, which are projected to worsen in the coming years due to population growth and climate change. Human activities such as water overuse and water pollution have compounded significantly the water crisis that exists today. Hundreds of millions of people lack access to safe drinking water, and billions of people lack access to improved sanitation as simple as a pit latrine. As a result, nearly two million people die every year from diarrheal diseases and 90% of those deaths occur among children under the age of 5. Most of these are easily prevented deaths.

Water Reservoirs and Water Cycle

Water is the only common substance that occurs naturally on earth in three forms: solid, liquid and gas. It is distributed in various locations, called water reservoirs. The oceans are by far the largest of the reservoirs with about 97% of all water but that water is too saline for most human uses (Figure $Page 9.1.1$). Ice caps and glaciers are the largest reservoirs of fresh water but this water is inconveniently located, mostly in Antarctica and Greenland. Shallow groundwater is the largest reservoir of usable fresh water. Although rivers and lakes are the most heavily used water resources, they represent only a tiny amount of the world's water. If all of world's water was shrunk to the size of 1 gallon, then the total amount of fresh water would be about 1/3 cup, and the amount of readily usable fresh water would be 2 tablespoons.

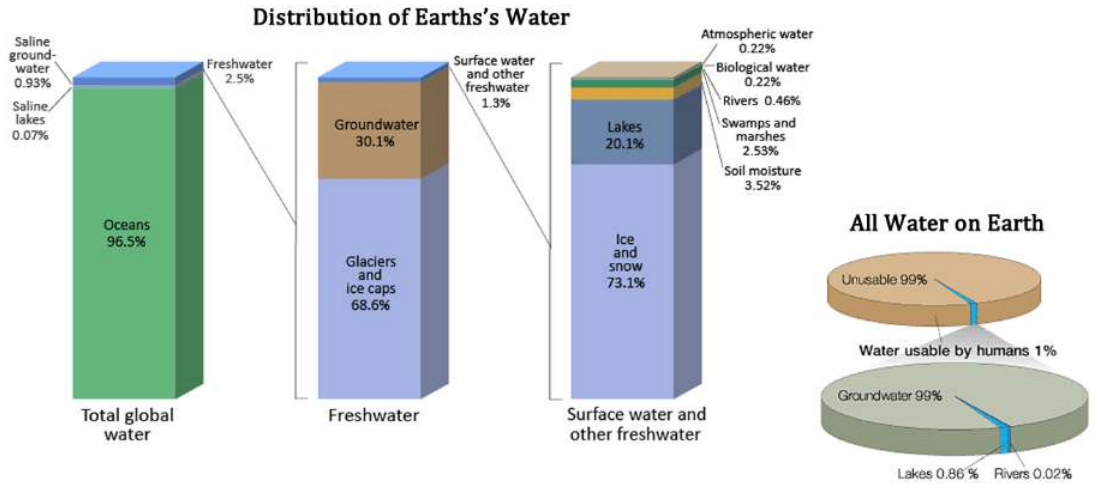


Figure $Page 9.1.1$. Earth's Water Reservoirs. Bar chart Distribution of Earth's water including total global water, fresh water, and surface water and other fresh water and Pie chart Water usable by humans and sources of usable water. Source: United States Geographical Survey

Igor Skiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources

The **water** (or hydrologic) **cycle** (that was covered in Chapter 3.2) shows the movement of water through different reservoirs, which include oceans, atmosphere, glaciers, groundwater, lakes, rivers, and biosphere. Solar energy and gravity drive the motion of water in the water cycle. Simply put, the water cycle involves water moving from oceans, rivers, and lakes to the atmosphere by evaporation, forming clouds. From clouds, it falls as precipitation (rain and snow) on both water and land. The water on land can either return to the ocean by surface runoff, rivers, glaciers, and subsurface groundwater flow, or return to the atmosphere by evaporation or **transpiration** (loss of water by plants to the atmosphere).

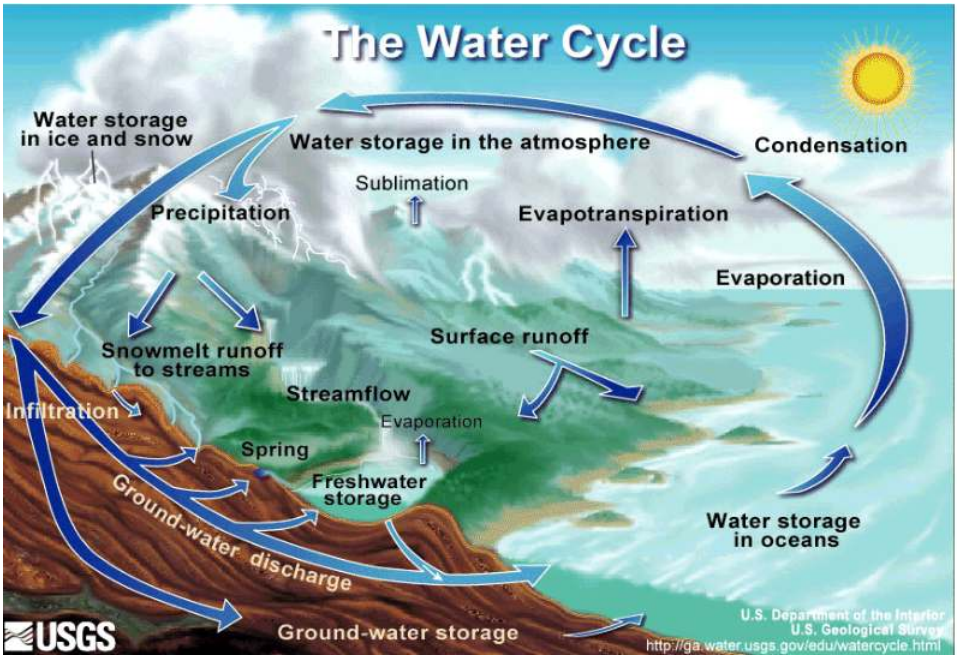


Figure $Page 9.1.2$. The Water Cycle. Arrows depict movement of water to different reservoirs located above, at, and below Earth's surface. Source: United States Geological Survey

An important part of the water cycle is how water varies in salinity, which is the abundance of dissolved ions in water. The saltwater in the oceans is highly saline, with about 35,000 mg of dissolved ions per liter of seawater. **Evaporation** (where water changes from liquid to gas at ambient temperatures) is a distillation process that produces nearly pure water with almost no dissolved ions. As water vaporizes, it leaves the dissolved ions in the original liquid phase. Eventually, **condensation** (where water changes from gas to liquid) forms clouds and sometimes precipitation (rain and snow). After rainwater falls onto land, it dissolves minerals in rock and soil, which increases its salinity. Most lakes, rivers, and near-surface groundwater have a relatively low salinity and are called freshwater. The next several sections discuss important parts of the water cycle relative to fresh water resources.

Primary Fresh Water Resources: Precipitation

Precipitation levels are unevenly distributed around the globe, affecting fresh water availability (Figure $Page 9.1.3$). More precipitation falls near the equator, whereas less precipitation tends to fall near 30 degrees north and south latitude, where the world's largest deserts are located. These rainfall and climate patterns are related to global wind circulation cells. The intense sunlight at the equator heats air, causing it to rise and cool, which decreases the ability of the air mass to hold water vapor and results in frequent rainstorms. Around 30 degrees north and south latitude, descending air conditions produce warmer air, which increases its ability to hold water vapor and results in dry conditions. Both the dry air conditions and the warm temperatures of these latitude belts favor evaporation. Global precipitation and climate patterns are also affected by the size of continents, major ocean currents, and mountains.

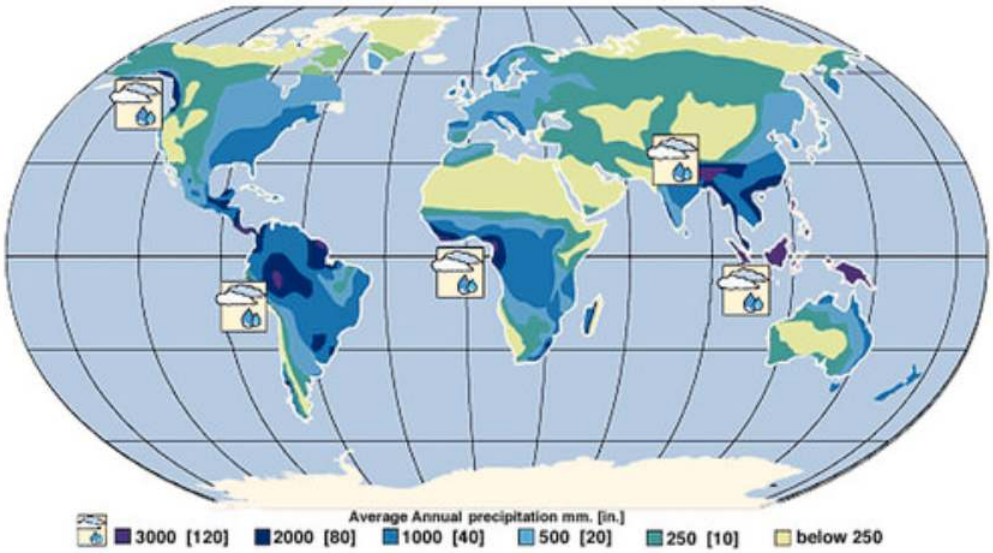


Figure $Page 9.1.3$. World Rainfall Map. The false-color map above shows the amount of rain that falls around the world. Areas of high rainfall include Central and South America, western Africa, and Southeast Asia. Since these areas receive so much rainfall, they are where most of the world's rainforests grow. Areas with very little rainfall usually turn into deserts. The desert areas include North Africa, the Middle East, western North America, and Central Asia. Source: United States Geological Survey Earth Forum, Houston Museum Natural Science

Surface Water Resources: Rivers, Lakes, Glaciers



Figure $Page 9.1.4$. Surface Runoff Surface runoff, part of overland flow in the water cycle Source: James M. Pease at Wikimedia Commons

Flowing water from rain and melted snow on land enters river channels by surface runoff (Figure $Page 9.1.4$) and groundwater seepage (Figure $Page 9.1.5$). **River discharge** describes the volume of water moving through a river channel over time (Figure $Page 9.1.6$). The relative contributions of surface runoff vs. groundwater seepage to river discharge depend on precipitation patterns, vegetation, topography, land use, and soil characteristics. Soon after a heavy rainstorm, river discharge increases due to surface runoff. The steady normal flow of river water is mainly from groundwater that discharges into the river. Gravity pulls river water downhill toward the ocean. Along the way the moving water of a river can erode soil particles and dissolve minerals. Groundwater also contributes a large amount of the dissolved minerals in river water. The geographic area drained by a river and its tributaries is called a **drainage basin** or **watershed**. The Mississippi River drainage basin includes approximately 40% of the U.S., a measure

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that includes the smaller drainage basins, such as the Ohio River and Missouri River that help to comprise it. Rivers are an important water resource for irrigation of cropland and drinking water for many cities around the world. Rivers that have had international disputes over water supply include the Colorado (Mexico, southwest U.S.), Nile (Egypt, Ethiopia, Sudan), Euphrates (Iraq, Syria, Turkey), Ganges (Bangladesh, India), and Jordan (Israel, Jordan, Syria).



Figure $Page 9.1.5$. Groundwater Seepage. Groundwater seepage can be seen in Box Canyon in Idaho, where approximately 10 cubic meters per second of seepage emanates from its vertical headwall. Source: NASA

In addition to rivers, lakes can also be an excellent source of freshwater for human use. They usually receive water from surface runoff and groundwater discharge. They tend to be short-lived on a geological time-scale because they are constantly filling in with sediment supplied by rivers. Lakes form in a variety of ways including glaciation, recent tectonic uplift (e.g., Lake Tanganyika, Africa), and volcanic eruptions (e.g., Crater Lake, Oregon). People also create artificial lakes (**reservoirs**) by damming rivers. Large changes in climate can result in major changes in a lake's size. As Earth was coming out of the last Ice Age about 15,000 years ago, the climate in the western U.S. changed from cool and moist to warm and arid, which caused more than 100 large lakes to disappear. The Great Salt Lake in Utah is a remnant of a much larger lake called Lake Bonneville.



Figure $Page 9.1.6$. River Discharge Colorado River, U.S.. Rivers are part of overland flow in the water cycle and an important surface water resource. Source: Gonzo fan2007 at

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Wikimedia Commons. Figure $Page 9.1.7$. Mountain Glacier in Argentina Glaciers are the largest reservoir of fresh water but they are not used much as a water resource directly by society because of their distance from most people. Source: Luca Galuzzi – www.galuzzi.it

Groundwater Resources

Although most people in the world use surface water, groundwater is a much larger reservoir of usable fresh water, containing more than 30 times more water than rivers and lakes combined. Groundwater is a particularly important resource in arid climates, where surface water may be scarce. In addition, groundwater is the primary water source for rural homeowners, providing 98% of that water demand in the U.S.. **Groundwater** is water located in small spaces, called **pore space**, between mineral grains and fractures in subsurface earth materials (rock or sediment). Most groundwater originates from rain or snowmelt, which infiltrates the ground and moves downward until it reaches the **saturated zone** (where groundwater completely fills pore spaces in earth materials).

Other sources of groundwater include seepage from surface water (lakes, rivers, reservoirs, and swamps), surface water deliberately pumped into the ground, irrigation, and underground wastewater treatment systems (septic tanks). **Recharge areas** are locations where surface water infiltrates the ground rather than running into rivers or evaporating. Wetlands, for example, are excellent recharge areas. A large area of sub-surface, porous rock that holds water is an aquifer. Aquifers are commonly drilled, and wells installed, to provide water for agriculture and personal use.

Water Use in the U.S. and World

People need water, oftentimes large quantities, to produce the food, energy, and mineral resources they use. Consider, for example, these approximate water requirements for some things people in the developed world use every day: one tomato = 3 gallons; one kilowatt-hour of electricity from a thermoelectric power plant = 21 gallons; one loaf of bread = 150 gallons; one pound of beef = 1,600 gallons; and one ton of steel = 63,000 gallons. Human beings require only about 1 gallon per day to survive, but a typical person in a U.S. household uses approximately 100 gallons per day, which includes cooking, washing dishes and clothes, flushing the toilet, and bathing. The **water demand** of an area is a function of the population and other uses of water.

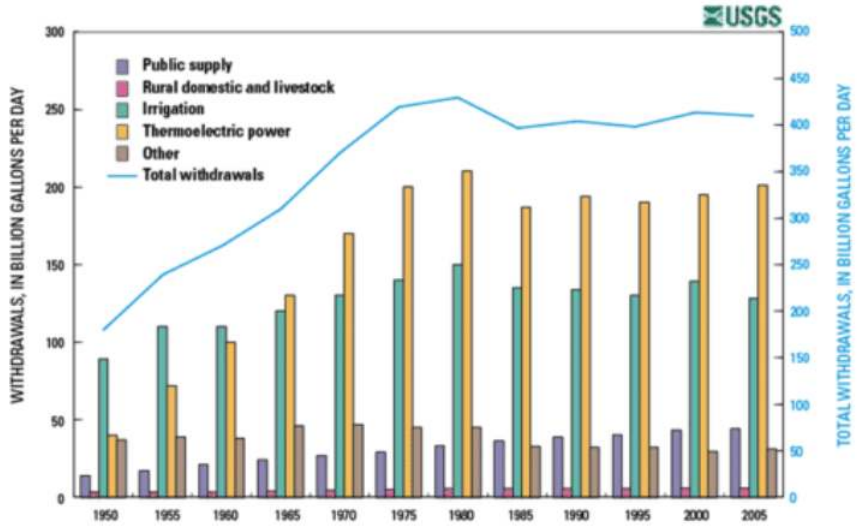


Figure $Page 9.1.8$. Trends in Total Water Withdrawals by Water-use Category, 1950-2005 Trends in total water withdrawals in the U.S. from 1950 to 2005 by water use category, including bars for thermoelectric power, irrigation, public water supply, and rural domestic and livestock. Thin blue line represents total water withdrawals using vertical scale on right. Source: United States Geological Survey

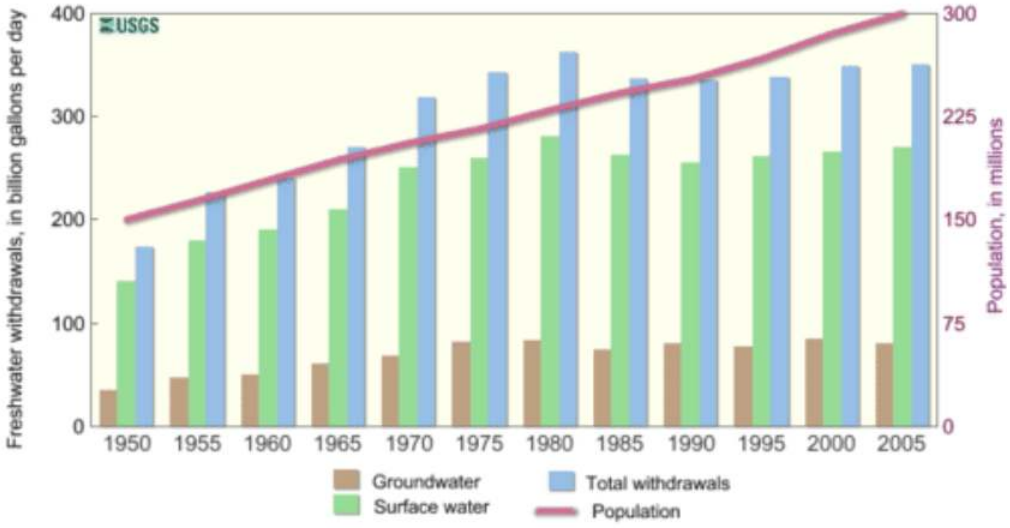


Figure $Page 9.1.9$. Trends in Source of Fresh Water Withdrawals in the U.S. from 1950 to 2005 Trends in source of fresh water withdrawals in the U.S. from 1950 to 2005, including bars for surface water, groundwater, and total water. Red line gives U.S. population using vertical scale on right. Source: United States Geological Survey

Global total water use is steadily increasing at a rate greater than world population growth (Figure $Page 9.1.10$). During the 20th century global population tripled and water demand grew by a factor of six. The increase in global water demand beyond the rate of population growth is due to improved standard of living without an offset by water conservation. Increased production of goods and energy entails a large increase in water demand. The major global water uses are irrigation (68%), public supply (21%), and industry (11%).

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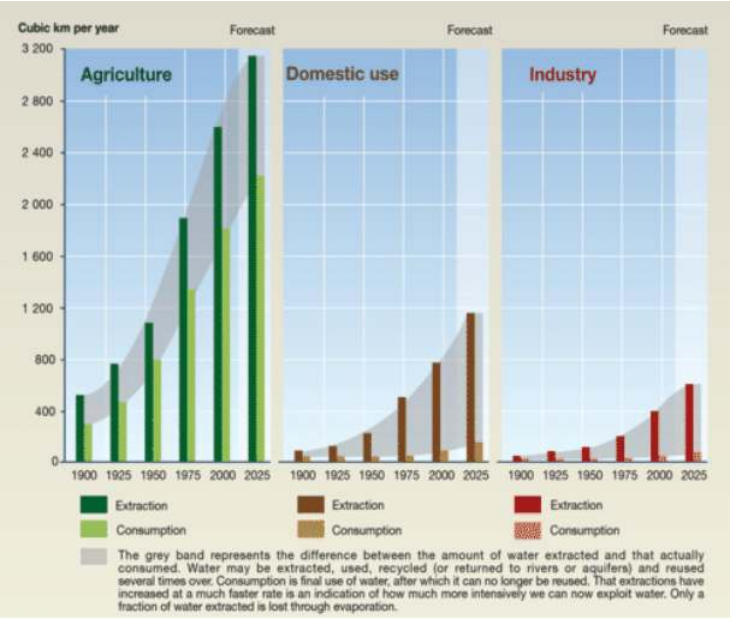


Figure $Page 9.1.10$. Trends in World Water Use from 1900 to 2000 and Projected to 2025 For each water major use category, including trends for agriculture, domestic use, and industry. Darker colored bar represents total water extracted for that use category and lighter colored bar represents water consumed (i.e., water that is not quickly returned to surface water or groundwater system) for that use category. Source: Igor A. Shiklomanow, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999

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Page 9.2: Water Supply Problems and Solutions

Water Supply Problems: Resource Depletion

As groundwater is pumped from water wells, there usually is a localized drop in the water table around the well called a cone of depression. When there are a large number of wells that have been pumping water for a long time, the regional water table can drop significantly. This is called **groundwater mining**, which can force the drilling of deeper, more expensive wells that commonly encounter more saline groundwater. Rivers, lakes, and artificial lakes (reservoirs) can also be depleted due to overuse. Some large rivers, such as the Colorado in the U.S. and Yellow in China, run dry in some years. The case history of the Aral Sea discussed later in this chapter involves depletion of a lake. Finally, glaciers are being depleted due to accelerated melting associated with global warming over the past century.

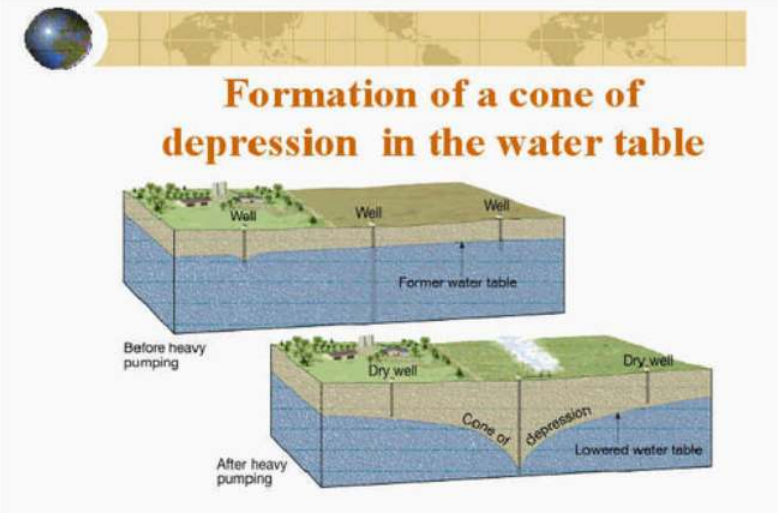


Figure $Page 9.2.1$. Formation of a Cone of Depression around a Pumping Water Well Source: Fayette County Groundwater Conservation District, TX

Another water resource problem associated with groundwater mining is saltwater intrusion, where overpumping of fresh water aquifers near ocean coastlines causes saltwater to enter fresh water zones. The drop of the water table around a **cone of depression** in an unconfined aquifer can change the direction of regional groundwater flow, which could send nearby pollution toward the pumping well instead of away from it. Finally, problems of **subsidence** (gradual sinking of the land surface over a large area) and **sinkholes** (rapid sinking of the land surface over a small area) can develop due to a drop in the water table.

Water Supply Crisis

The **water crisis** refers to a global situation where people in many areas lack access to sufficient water, clean water, or both. This section describes the global situation involving water shortages, also called **water stress**. In general, water stress is greatest in areas with very low precipitation (major deserts), large population density (e.g., India), or both. Future global warming could worsen the water crisis by shifting precipitation patterns away from humid areas and by melting mountain glaciers that recharge rivers downstream. Melting glaciers will also contribute to rising sea level, which will worsen saltwater intrusion in aquifers near ocean coastlines.

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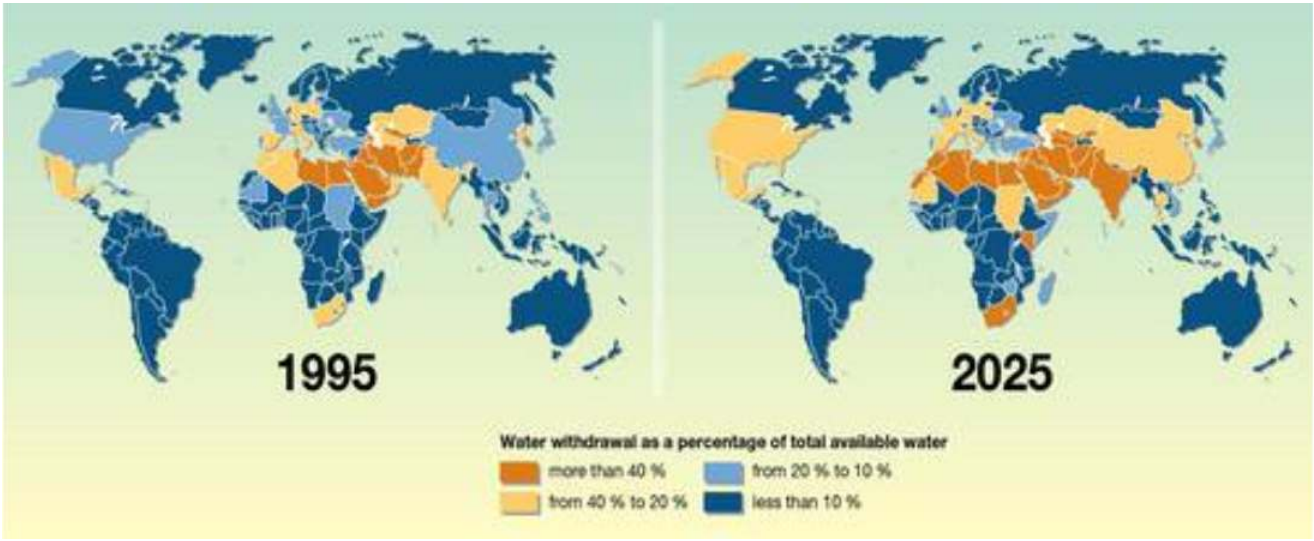


Figure $Page 9.2.2$. Countries Facing Water Stress in 1995 and Projected in 2025 Water stress is defined as having a high percentage of water withdrawal compared to total available water in the area. Source: Philippe Rekacewicz (Le Monde diplomatique), February 2006

According to a 2006 report by the United Nations Development Programme, 700 million people (11% of the world's population) lived with water stress. Most of them live in the Middle East and North Africa. By 2025, the report projects that more than 3 billion people (about 40% of the world's population) will live in water-stressed areas with the large increase coming mainly from China and India. The water crisis will also impact food production and our ability to feed the ever-growing population. We can expect future global tension and even conflict associated with water shortages and pollution. Historic and future areas of water conflict include the Middle East (Euphrates and Tigris River conflict among Turkey, Syria, and Iraq; Jordan River conflict among Israel, Lebanon, Jordan, and the Palestinian territories), Africa (Nile River conflict among Egypt, Ethiopia, and Sudan), Central Asia (Aral Sea conflict among Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan), and south Asia (Ganges River conflict between India and Pakistan).

Sustainable Solutions to the Water Supply Crisis?

The current and future water crisis described above requires multiple approaches to extending our fresh water supply and moving towards sustainability. Some of the longstanding traditional approaches include dams and aqueducts.



Figure $Page 9.2.3$. Hoover Dam, Nevada, U.S. Hoover Dam, Nevada, U.S.. Behind the dam is Lake Mead, the largest reservoir in U.S.. White band reflects the lowered water levels in the reservoir due to drought conditions

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from 2000 – 2010. Source: Cygnusloop99 at Wikimedia Commons

Reservoirs that form behind dams in rivers can collect water during wet times and store it for use during dry spells. They also can be used for urban water supplies. Other benefits of dams and reservoirs are hydroelectricity, flood control, and recreation. Some of the drawbacks are evaporative loss of water in arid climates, downstream river channel erosion, and impact on the ecosystem including a change from a river to lake habitat and interference with migration and spawning of fish.

Aqueducts can move water from where it is plentiful to where it is needed. Aqueducts can be controversial and politically difficult especially if the water transfer distances are large. One drawback is the water diversion can cause drought in the area from where the water is drawn. For example, Owens Lake and Mono Lake in central California began to disappear after their river flow was diverted to the Los Angeles aqueduct. Owens Lake remains almost completely dry, but Mono Lake has recovered more significantly due to legal intervention.

One method that can actually increase the amount of fresh water on Earth is **desalination**, which involves removing dissolved salt from seawater or saline groundwater. There are several ways to desalinate seawater including boiling, filtration, and electrodialysis. All of these procedures are moderately to very expensive and require considerable energy input, making the water produced much more expensive than fresh water from conventional sources. In addition, the process creates highly saline wastewater, which must be disposed of and creates significant environmental impact. Desalination is most common in the Middle East, where energy from oil is abundant but water is scarce.



Figure $Page 9.2.4$. The California Aqueduct California Aqueduct in southern California, U.S. Source: David Jordan at en.Wikipedia

Conservation means using less water and using it more efficiently. Around the home, conservation can involve both engineered features, such as high-efficiency clothes washers and low-flow showers and toilets, as well as behavioral decisions, such as growing native vegetation that require little irrigation in desert climates, turning off the water while you brush your teeth, and fixing leaky faucets.

Rainwater harvesting involves catching and storing rainwater for reuse before it reaches the ground. Another important technique is **efficient irrigation,** which is extremely important because irrigation accounts for a much larger water demand than public water supply. Water conservation strategies in agriculture include growing crops in areas where the natural rainfall can support them, more efficient irrigation systems such as drip systems that minimize losses due to evaporation, no-till farming that reduces evaporative losses by covering the soil, and reusing treated wastewater from sewage treatment plants. Recycled wastewater has also been used to recharge aquifers.

Suggested Supplementary Reading:

Weiss, K.R. 2018. Drying Lakes. *National Geographic.* March. p. 108-133.

This article documents how many lakes across the globe are drying up, the reasons why, and the effect on humans. Overuse and a warming climate threaten lakes that provide sustenance and jobs for humans, while also providing critical habitat for animals.

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Page 9.3: Water Pollution

The global water crisis also involves water pollution. For water to be useful for drinking and irrigation, it must not be polluted beyond certain thresholds. According to the World Health Organization, in 2008 approximately 880 million people in the world (or 13% of world population) did not have access to safe drinking water. At the same time, about 2.6 billion people (or 40% of world population) lived without improved sanitation, which is defined as having access to a public sewage system, septic tank, or even a simple pit latrine. Each year approximately 1.7 million people die from diarrheal diseases associated with unsafe drinking water, inadequate sanitation, and poor hygiene. Almost all of these deaths are in developing countries, and around 90% of them occur among children under the age of 5 (Figure *Page*9.3.1). Compounding the water crisis is the issue of social justice; poor people more commonly lack clean water and sanitation than wealthy people in similar areas. Globally, improving water safety, sanitation, and hygiene could prevent up to 9% of all disease and 6% of all deaths.

In addition to the global waterborne disease crisis, chemical pollution from agriculture, industry, cities, and mining threatens global water quality. Some chemical pollutants have serious and well-known health effects, whereas many others have poorly known long-term health effects. In the U.S. currently more than 40,000 water bodies fit the definition of “impaired” set by EPA, which means they could neither support a healthy ecosystem nor meet water quality standards. In Gallup public polls conducted over the past decade Americans consistently put water pollution and water supply as the top environmental concerns over issues such as air pollution, deforestation, species extinction, and global warming.

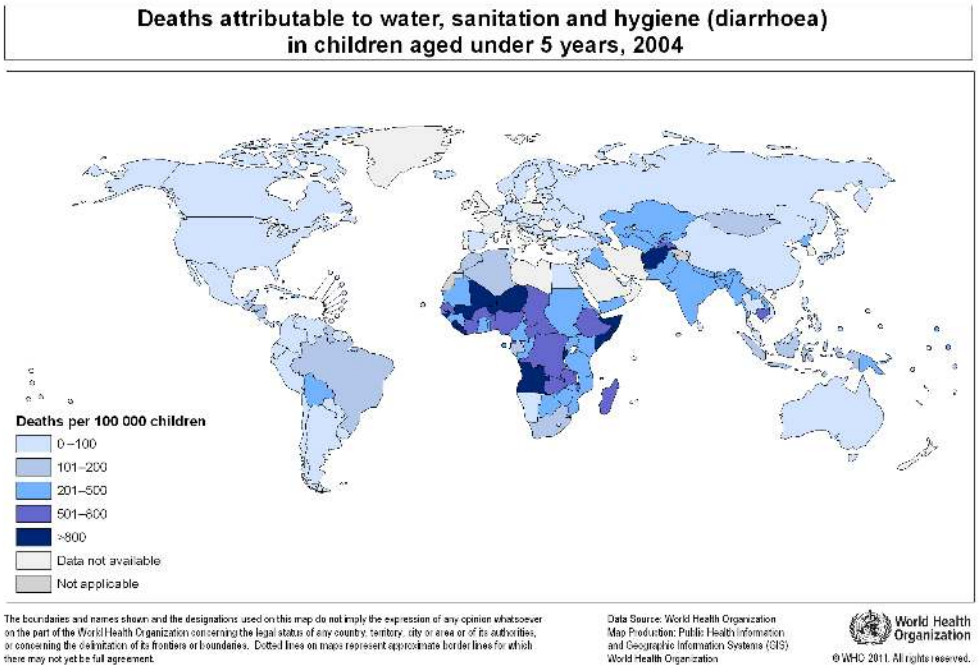


Figure *Page*9.3.1. This work was created by the *World Health Organization*.

Any natural water contains dissolved chemicals, some of which are important human nutrients while others can be harmful to human health. The concentration of a water pollutant is commonly given in very small units such as parts per million (**ppm**) or even parts per billion (**ppb**). An arsenic concentration of 1 ppm means 1 part of arsenic per million parts of water. This is equivalent to one drop of arsenic in 50 liters of water. To give you a different perspective on appreciating small concentration units, converting 1 ppm to length units is 1 cm (0.4 in) in 10 km (6 miles) and converting 1 ppm to time units is 30 seconds in a year. **Total dissolved solids** (TDS) represent the total amount of dissolved material in water. Average TDS values for rainwater, river water, and seawater are about 4 ppm, 120 ppm, and 35,000 ppm, respectively.

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Figure $Page 9.3.2$. Water Pollution. Obvious water pollution in the form of floating debris; invisible water pollutants sometimes can be much more harmful than visible ones. Source: Stephen Codrington at Wikimedia Commons

Water pollution is the contamination of water by an excess amount of a substance that can cause harm to human beings and/or the ecosystem. The level of water pollution depends on the abundance of the pollutant, the ecological impact of the pollutant, and the use of the water. Pollutants are derived from biological, chemical, or physical processes. Although natural processes such as volcanic eruptions or evaporation sometimes can cause water pollution, most pollution is derived from human, land-based activities (Figure $Page 9.3.2$). Water pollutants can move through different water reservoirs, as the water carrying them progresses through stages of the water cycle (Figure $Page 9.3.3$). **Water residence time** (the average time that a water molecule spends in a water reservoir) is very important to pollution problems because it affects pollution potential. Water in rivers has a relatively short residence time, so pollution usually is there only briefly. Of course, pollution in rivers may simply move to another reservoir, such as the ocean, where it can cause further problems. Groundwater is typically characterized by slow flow and longer residence time, which can make groundwater pollution particularly problematic. Finally, **pollution residence time** can be much greater than the water residence time because a pollutant may be taken up for a long time within the ecosystem or absorbed onto sediment.

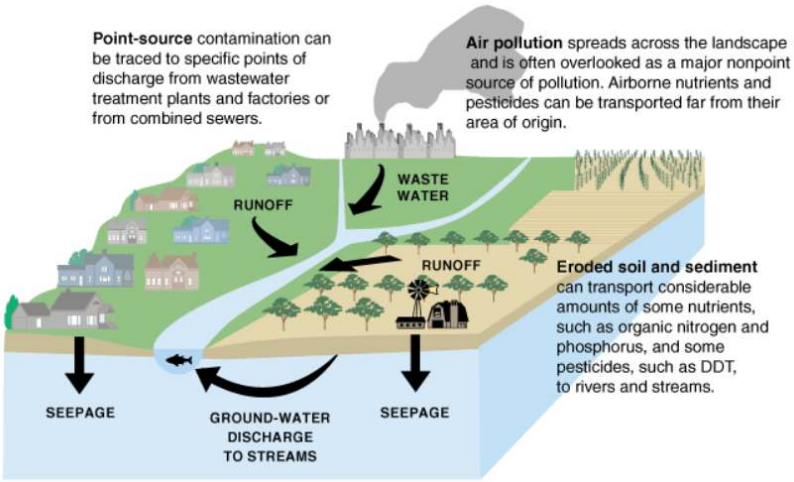


Figure $Page 9.3.3$. Sources of Water Contamination. Sources of some water pollutants and movement of pollutants into different water reservoirs of the water cycle. Source: U.S. Geological Survey

Pollutants enter water supplies from **point sources**, which are readily identifiable and relatively small locations, or **nonpoint sources**, which are large and more diffuse areas. Point sources of pollution include animal factory farms (Figure $Page 9.3.4$) that raise a large number and high density of livestock such as cows, pigs, and chickens. Also, pipes included are pipes from a factories

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or sewage treatment plants. Combined sewer systems that have a single set of underground pipes to collect both sewage and storm water runoff from streets for wastewater treatment can be major point sources of pollutants. During heavy rain, storm water runoff may exceed sewer capacity, causing it to back up and spilling untreated sewage directly into surface waters (Figure $Page9.3.5$).



Figure $Page9.3.4$. Large animal farms are often referred to as concentrated feeding operations (CFOs). These farms are considered potential point sources of pollution because untreated animal waste may enter nearby waterbodies as untreated sewage. Credit: ehp.gov

Nonpoint sources of pollution include agricultural fields, cities, and abandoned mines. Rainfall runs over the land and through the ground, picking up pollutants such as herbicides, pesticides, and fertilizer from agricultural fields and lawns; oil, antifreeze, animal waste, and road salt from urban areas; and acid and toxic elements from abandoned mines. Then, this pollution is carried into surface water bodies and groundwater. Nonpoint source pollution, which is the leading cause of water pollution in the U.S., is usually much more difficult and expensive to control than point source pollution because of its low concentration, multiple sources, and much greater volume of water.

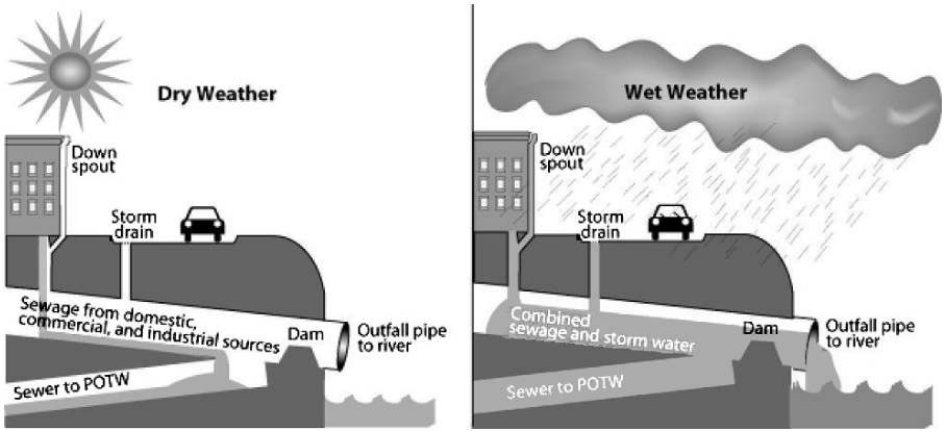


Figure $Page9.3.5$. Combined Sewer System A combined sewer system is a possible major point source of water pollution during heavy rain due to overflow of untreated sewage. During dry weather (and small storms), all flows are handled by the publicly owned treatment works (POTW). During large storms, the relief structure allows some of the combined stormwater and sewage to be discharged untreated to an adjacent water body. Source: U.S. Environmental Protection Agency at Wikimedia Commons

Types of Water Pollutants

Oxygen-demanding waste is an extremely important pollutant to ecosystems. Most surface water in contact with the atmosphere has a small amount of dissolved oxygen, which is needed by aquatic organisms for cellular respiration. Bacteria decompose dead organic matter and remove dissolved oxygen (O_2) according to the following reaction:

$$\text{organic matter} + O_2 \rightarrow CO_2 + H_2O \qquad \text{(Page 9.3.1)}$$

Too much decaying organic matter in water is a pollutant because it removes oxygen from water, which can kill fish, shellfish, and aquatic insects. The amount of oxygen used by **aerobic** (in the presence of oxygen) bacterial decomposition of organic matter is

called **biochemical oxygen demand** (BOD). The major source of dead organic matter in many natural waters is sewage; grass and leaves are smaller sources. An unpolluted water body with respect to BOD is a turbulent river that flows through a natural forest. Turbulence continually brings water in contact with the atmosphere where the O_2 content is restored. The dissolved oxygen content in such a river ranges from 10 to 14 ppm O_2, BOD is low, and clean-water fish such as trout. A polluted water body with respect to oxygen is a stagnant deep lake in an urban setting with a combined sewer system. This system favors a high input of dead organic carbon from sewage overflows and limited chance for water circulation and contact with the atmosphere. In such a lake, the dissolved O_2 content is ≤5 ppm O_2, BOD is high, and low O_2-tolerant fish, such as carp and catfish dominate.

Excessive plant nutrients, particularly nitrogen (N) and phosphorous (P), are pollutants closely related to oxygen-demanding waste. Aquatic plants require about 15 nutrients for growth, most of which are plentiful in water. N and P are called **limiting nutrients**, however, because they usually are present in water at low concentrations and therefore restrict the total amount of plant growth. This explains why N and P are major ingredients in most fertilizer. High concentrations of N and P from human sources (mostly agricultural and urban runoff including fertilizer, sewage, and phosphorus-based detergent) can cause cultural **eutrophication**, which leads to the rapid growth of aquatic producers, particularly algae. Thick mats of floating algae or rooted plants lead to a form of water pollution that damages the ecosystem by clogging fish gills and blocking sunlight. A small percentage of algal species produce toxins that can kill animals, including humans. Exponential growths of these algae are called **harmful algal blooms**. When the prolific algal layer dies, it becomes oxygen-demanding waste, which can create very low O_2 concentrations in the water (< 2 ppm O_2), a condition called **hypoxia.** This results in a **dead zone** because it causes death from asphyxiation to organisms that are unable to leave that environment. An estimated 50% of lakes in North America, Europe, and Asia are negatively impacted by cultural eutrophication. In addition, the size and number of marine hypoxic zones have grown dramatically over the past 50 years including a very large dead zone located offshore Louisiana in the Gulf of Mexico. Cultural eutrophication and hypoxia are difficult to combat, because they are caused primarily by nonpoint source pollution, which is difficult to regulate, and N and P, which are difficult to remove from wastewater.

Pathogens are disease-causing microorganisms, e.g., viruses, bacteria, parasitic worms, and protozoa, which cause a variety of intestinal diseases such as dysentery, typhoid fever, and cholera. Pathogens are the major cause of the water pollution crisis discussed at the beginning of this section. Unfortunately nearly a billion people around the world are exposed to waterborne pathogen pollution daily and around 1.5 million children mainly in underdeveloped countries die every year of waterborne diseases from pathogens. Pathogens enter water primarily from human and animal fecal waste due to inadequate sewage treatment. In many underdeveloped countries, sewage is discharged into local waters either untreated or after only rudimentary treatment. In developed countries untreated sewage discharge can occur from overflows of combined sewer systems, poorly managed livestock factory farms, and leaky or broken sewage collection systems. Water with pathogens can be remediated by adding chlorine or ozone, by boiling, or by treating the sewage in the first place.

Oil spills are another kind of organic pollution. Oil spills can result from supertanker accidents such as the Exxon Valdez in 1989, which spilled 10 million gallons of oil into the rich ecosystem of coastal Alaska and killed massive numbers of animals. The largest marine oil spill was the Deepwater Horizon disaster, which began with a natural gas explosion (Figure $Page9.3.6$) at an oil well 65 km offshore of Louisiana and flowed for 3 months in 2010, releasing an estimated 200 million gallons of oil. The worst oil spill ever occurred during the Persian Gulf war of 1991, when Iraq deliberately dumped approximately 200 million gallons of oil in offshore Kuwait and set more than 700 oil well fires that released enormous clouds of smoke and acid rain for over nine months.



Figure $Page 9.3.6$. Deepwater Horizon Explosion Boats fighting the fire from an explosion at the Deepwater Horizon drilling rig in Gulf of Mexico offshore Louisiana on April 20, 2010. Source: United States Coast Guard via Wikimedia Commons

During an oil spill on water, oil floats to the surface because it is less dense than water, and the lightest hydrocarbons evaporate, decreasing the size of the spill but polluting the air. Then, bacteria begin to decompose the remaining oil, in a process that can take many years. After several months only about 15% of the original volume may remain, but it is in thick asphalt lumps, a form that is particularly harmful to birds, fish, and shellfish. Cleanup operations can include skimmer ships that vacuum oil from the water surface (effective only for small spills), controlled burning (works only in early stages before the light, ignitable part evaporates but also pollutes the air), **dispersants** (detergents that break up oil to accelerate its decomposition, but some dispersants may be toxic to the ecosystem), and bioremediation (adding microorganisms that specialize in quickly decomposing oil, but this can disrupt the natural ecosystem).

Toxic chemicals involve many different kinds and sources, primarily from industry and mining. General kinds of toxic chemicals include hazardous chemicals and persistent organic pollutants that include DDT (pesticide), dioxin (herbicide by-product), and PCBs (polychlorinated biphenyls, which were used as a liquid insulator in electric transformers). **Persistent organic pollutants** (POPs) are long-lived in the environment, biomagnify through the food chain, and can be toxic. Another category of toxic chemicals includes radioactive materials such as cesium, iodine, uranium, and radon gas, which can result in long-term exposure to radioactivity if it gets into the body. A final group of toxic chemicals is heavy metals such as lead, mercury, arsenic, cadmium, and chromium, which can accumulate through the food chain. Heavy metals are commonly produced by industry and at metallic ore mines. Arsenic and mercury are discussed in more detail below.

Arsenic (As) has been famous as an agent of death for many centuries. Only recently have scientists recognized that health problems can be caused by drinking small arsenic concentrations in water over a long time. It enters the water supply naturally from weathering of arsenic-rich minerals and from human activities such as coal burning and smelting of metallic ores. The worst case of arsenic poisoning occurred in the densely populated impoverished country of Bangladesh, which had experienced 100,000s of deaths from diarrhea and cholera each year from drinking surface water contaminated with pathogens due to improper sewage treatment. In the 1970s the United Nations provided aid for millions of shallow water wells, which resulted in a dramatic drop in pathogenic diseases. Unfortunately, many of the wells produced water naturally rich in arsenic. Tragically, there are an estimated 77 million people (about half of the population) who inadvertently may have been exposed to toxic levels of arsenic in Bangladesh as a result. The World Health Organization has called it the largest mass poisoning of a population in history.

Mercury (Hg) is used in a variety of electrical products, such as dry cell batteries, fluorescent light bulbs, and switches, as well as in the manufacture of paint, paper, vinyl chloride, and fungicides. Mercury acts on the central nervous system and can cause loss of sight, feeling, and hearing as well as nervousness, shakiness, and death. Like arsenic, mercury enters the water supply naturally from weathering of mercury-rich minerals and from human activities such as coal burning and metal processing. A famous mercury poisoning case in Minamata, Japan involved methylmercury-rich industrial discharge that caused high Hg levels in fish. People in

the local fishing villages ate fish up to three times per day for over 30 years, which resulted in over 2,000 deaths. During that time the responsible company and national government did little to mitigate, help alleviate, or even acknowledge the problem.

Hard water contains abundant calcium and magnesium, which reduces its ability to develop soapsuds and enhances scale (calcium and magnesium carbonate minerals) formation on hot water equipment. Water softeners remove calcium and magnesium, which allows the water to lather easily and resist scale formation. Hard water develops naturally from the dissolution of calcium and magnesium carbonate minerals in soil; it does not have negative health effects in people.

Groundwater pollution can occur from underground sources and all of the pollution sources that contaminate surface waters. Common sources of groundwater pollution are leaking underground storage tanks for fuel, septic tanks, agricultural activity, landfills, and fossil fuel extraction. Common groundwater pollutants include nitrate, pesticides, volatile organic compounds, and petroleum products. Another troublesome feature of groundwater pollution is that small amounts of certain pollutants, e.g., petroleum products and organic solvents, can contaminate large areas. In Denver, Colorado 80 liters of several organic solvents contaminated 4.5 trillion liters of groundwater and produced a 5 km long contaminant plume. A major threat to groundwater quality is from underground fuel storage tanks. Fuel tanks commonly are stored underground at gas stations to reduce explosion hazards. Before 1988 in the U.S. these storage tanks could be made of metal, which can corrode, leak, and quickly contaminate local groundwater. Now, leak detectors are required and the metal storage tanks are supposed to be protected from corrosion or replaced with fiberglass tanks. Currently there are around 600,000 underground fuel storage tanks in the U.S. and over 30% still do not comply with EPA regulations regarding either release prevention or leak detection.

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Page 9.4: Water Treatment

Resolution of the global water pollution crisis requires multiple approaches to improve the quality of our fresh water and move towards sustainability. The most deadly form of water pollution, pathogenic microorganisms that cause waterborne diseases, kills almost 2 million people in underdeveloped countries every year. The best strategy for addressing this problem is proper sewage (wastewater) treatment. Untreated sewage is not only a major cause of pathogenic diseases, but also a major source of other pollutants, including oxygen-demanding waste, nutrients (N and P, particularly), and toxic heavy metals. Wastewater treatment is done at a sewage treatment plant in urban areas and through a septic tank system in rural areas.

The main purpose of **sewage (wastewater) treatment** is to remove organic matter (oxygen-demanding waste) and kill bacteria. Special methods also can be used to remove nutrients and other pollutants. The numerous steps at a conventional sewage treatment plant include **pretreatment** (screening and removal of sand and gravel), **primary treatment** (settling or floatation to remove organic solids, fat, and grease), **secondary treatment** (aerobic bacterial decomposition of organic solids), **tertiary treatment** (bacterial decomposition of nutrients and filtration), **disinfection** (treatment with chlorine, ozone, ultraviolet light, or bleach to kill most microbes), and either **discharge** to surface waters (usually a local river) or reuse for some other purpose, such as irrigation, habitat preservation, and artificial groundwater recharge (Figure $Page 9.4.1$).

The concentrated organic solid produced during primary and secondary treatment is called **sludge**, which is treated in a variety of ways including landfill disposal, incineration, use as fertilizer, and anaerobic bacterial decomposition, which is done in the absence of oxygen. Anaerobic decomposition of sludge produces methane gas, which can be used as an energy source. To reduce water pollution problems, separate sewer systems (where street runoff goes to rivers and only wastewater goes to a wastewater treatment plant) are much better than combined sewer systems, which can overflow and release untreated sewage into surface waters during heavy rain. Some cities such as Chicago, Illinois have constructed large underground caverns and also use abandoned rock quarries to hold storm sewer overflow. After the rain stops, the stored water goes to the sewage treatment plant for processing.

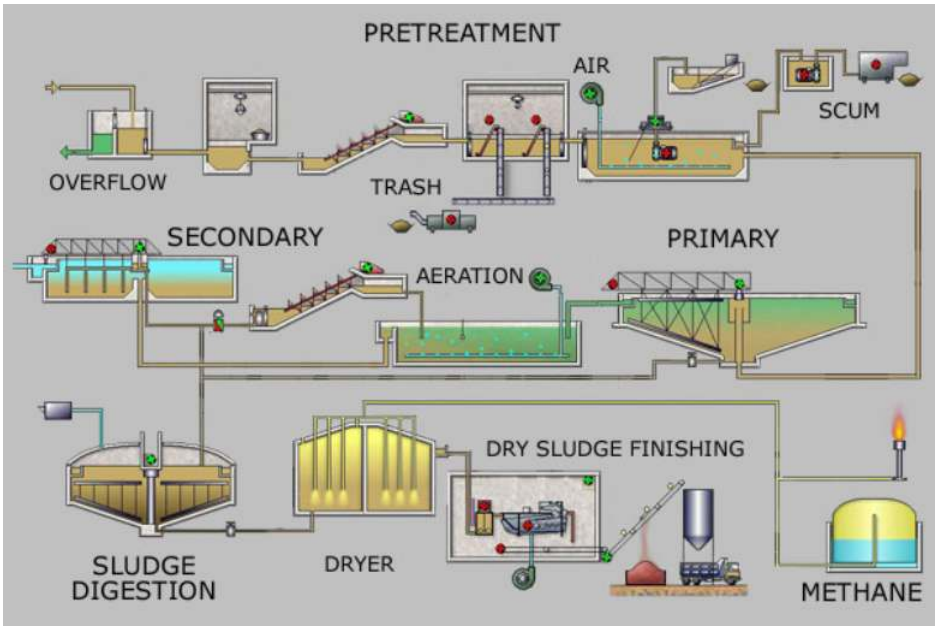


Figure $Page 9.4.1$. Steps at a Sewage Treatment Plant The numerous processing steps at a conventional sewage treatment plant include pretreatment (screening and removal of sand and gravel), primary treatment (settling or floatation to remove organic solids, fat, and grease), secondary treatment (aerobic bacterial decomposition of organic solids), tertiary treatment (bacterial decomposition of nutrients and filtration), disinfection (treatment with chlorine, ozone, ultraviolet light, or bleach), and either discharge to surface waters (usually a local river) or reuse for some other purpose, such as irrigation, habitat preservation, and artificial groundwater recharge. Source: Leonard G.via Wikipedia

A **septic tank system** is an individual sewage treatment system for homes in typically rural settings. The basic components of a septic tank system (Figure $Page 9.4.2$) include a sewer line from the house, a septic tank (a large container where sludge settles to the bottom and microorganisms decompose the organic solids anaerobically), and the drain field (network of perforated pipes

where the clarified water seeps into the soil and is further purified by bacteria). Water pollution problems occur if the septic tank malfunctions, which usually occurs when a system is established in the wrong type of soil or maintained poorly.

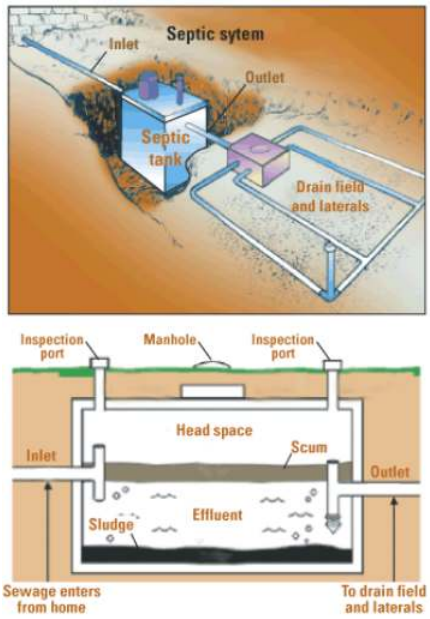


Figure $Page 9.4.2$. Septic System Septic tank system for sewage treatment. Source: United States Geological Survey

For many developing countries, financial aid is necessary to build adequate sewage treatment facilities. The World Health Organization estimates an estimated cost savings of between $3 and $34 for every $1 invested in clean water delivery and sanitation. The cost savings are from health care savings, gains in work and school productivity, and prevented deaths. Simple and inexpensive techniques for treating water at home include chlorination, filters, and solar disinfection. Another alternative is to use constructed wetlands technology (marshes built to treat contaminated water), which is simpler and cheaper than a conventional sewage treatment plant.

Bottled water is not a sustainable solution to the water crisis. Bottled water is not necessarily any safer than the U.S. public water supply, it costs on average about 700 times more than U.S. tap water, and every year it uses approximately 200 billion plastic and glass bottles that have a relatively low rate of recycling. Compared to tap water, it uses much more energy, mainly in bottle manufacturing and long-distance transportation. If you don't like the taste of your tap water, then please use a water filter instead of bottled water!

CLEAN WATER ACT



Figure $Page 9.4.3$. Cuyahoga River on fire. Source: National Oceanic and Atmospheric Administration

During the early 1900s rapid industrialization in the U.S. resulted in widespread water pollution due to free discharge of waste into surface waters. The Cuyahoga River in northeast Ohio caught fire numerous times, including a famous fire in 1969 that caught the nation's attention. In 1972 Congress passed one of the most important environmental laws in U.S. history, the Federal Water Pollution Control Act, which is more commonly called the **Clean Water Act**. The purpose of the Clean Water Act and later amendments is to maintain and restore water quality, or in simpler terms to make our water swimmable and fishable. It became illegal to dump pollution into surface water unless there was formal permission and U.S. water quality improved significantly as a result. More progress is needed because currently the EPA considers over 40,000 U.S. water bodies as impaired, most commonly due to pathogens, metals, plant nutrients, and oxygen depletion. Another concern is protecting groundwater quality, which is not yet addressed sufficiently by federal law.

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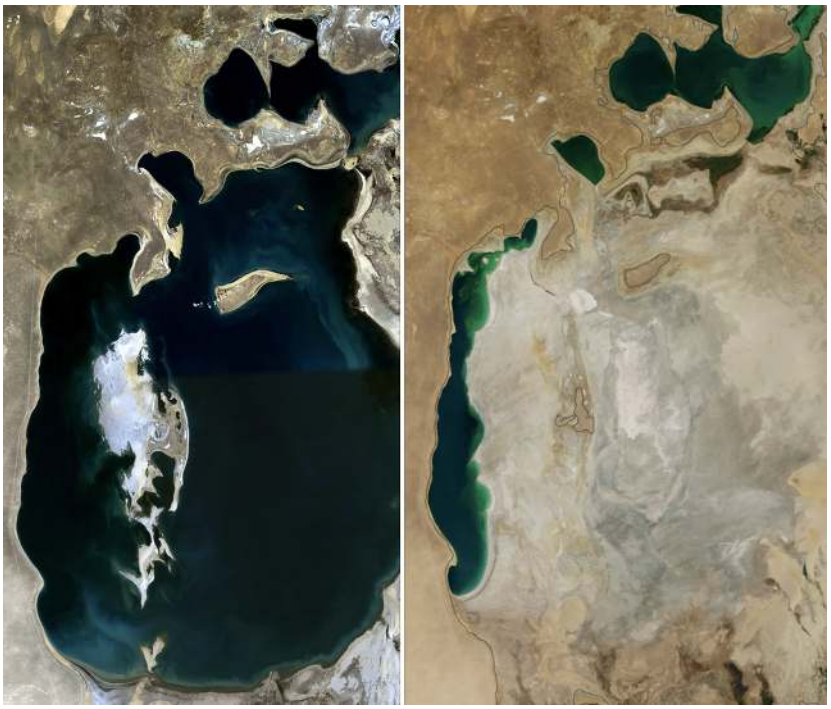
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Page 9.5: Case Study - The Aral Sea - Going, Going, Gone

The Aral Sea is a lake located east of the Caspian Sea between Uzbekistan and Kazakhstan in central Asia. This area is part of the Turkestan desert, which is the fourth largest desert in the world; it is produced from a rain shadow effect by Afghanistan's high mountains to the south. Due to the arid and seasonally hot climate there is extensive evaporation and limited surface waters in general. Summer temperatures can reach 60°C (140°F)! The water supply to the Aral Sea is mainly from two rivers, the Amu Darya and Syr Darya, which carry snow melt from mountainous areas.



A comparison of the Aral Sea in 1989 (left) and 2014 (right). Credit: This work is in the Public Domain, CC0

In the early 1960s, the then-Soviet Union diverted the Amu Darya and Syr Darya Rivers for irrigation of one of the driest parts of Asia to produce rice, melons, cereals, and especially cotton. The Soviets wanted cotton or white gold to become a major export. They were successful, and, today Uzbekistan is one of the world's largest exporters of cotton. Unfortunately, this action essentially eliminated any river inflow to the Aral Sea and caused it to disappear almost completely.



Figure $Page 9.5.2$. Map of Aral Sea Area Map shows lake size in 1960 and political boundaries of 2011. Countries in yellow are at least partially in Aral Sea drainage basin. Source: Wikimedia Commons

In 1960, Aral Sea was the fourth largest inland water body; only the Caspian Sea, Lake Superior, and Lake Victoria were larger. Since then, it has progressively shrunk due to evaporation and lack of recharge by rivers. Before 1965, the Aral Sea received 2060 km^3 of fresh water per year from rivers and by the early 1980s it received none. By 2007, the Aral Sea shrank to about 10% of its original size and its salinity increased from about 1% dissolved salt to about 10% dissolved salt, which is 3 times more saline than seawater. These changes caused an enormous environmental impact. A once thriving fishing industry is dead as are the 24 species of fish that used to live there; the fish could not adapt to the more saline waters. The current shoreline is tens of kilometers from former fishing towns and commercial ports. Large shing boats lie in the dried up lakebed of dust and salt. A frustrating part of the river diversion project is that many of the irrigation canals were poorly built, allowing abundant water to leak or evaporate. An increasing number of dust storms blow salt, pesticides, and herbicides into nearby towns causing a variety of respiratory illnesses including tuberculosis.



Figure $Page 9.5.3$. This abandoned ship lies in a dried up lake bed that was the Aral Sea near Aral, Kazakhstan Source: Staecker at Wikimedia Commons

The wetlands of the two river deltas and their associated ecosystems have disappeared. The regional climate is drier and has greater temperature extremes due to the absence of moisture and moderating influence from the lake. In 2003, some lake restoration work began on the northern part of the Aral Sea and it provided some relief by raising water levels and reducing salinity somewhat. The southern part of the Aral Sea has seen no relief and remains nearly completely dry. The destruction of the Aral Sea is one of the planet's biggest environmental disasters and it is caused entirely by humans. Lake Chad in Africa is another example of a massive lake that has nearly disappeared for the same reasons as the Aral Sea. Aral Sea and Lake Chad are the most extreme examples of large lakes destroyed by unsustainable diversions of river water. Other lakes that have shrunk significantly due to human diversions of water include the Dead Sea in the Middle East, Lake Manchar in Pakistan, and Owens Lake and Mono Lake, both in California.

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Page 9.6: Chapter Resources

Summary

Precipitation—a major control of fresh water availability—is unevenly distributed around the globe. More precipitation falls near the equator, and landmasses there are characterized by a tropical rainforest climate. Less precipitation tends to fall near 2030 north and south latitude, where the world's largest deserts are located. The water crisis refers to a global situation where people in many areas lack access to sufficient water or clean water or both. The current and future water crisis requires multiple approaches to extending our fresh water supply and moving towards sustainability. Some of the longstanding traditional approaches include dams and aqueducts. Water pollution is the contamination of water by an excess amount of a substance that can cause harm to human beings and the ecosystem. The level of water pollution depends on the abundance of the pollutant, the ecological impact of the pollutant, and the use of the water. The most deadly form of water pollution, pathogenic microorganisms that cause waterborne diseases, kills almost 2 million people in underdeveloped countries every year. Resolution of the global water pollution crisis requires multiple approaches to improve the quality of fresh water. The best strategy for addressing this problem is proper sewage treatment. Untreated sewage is not only a major cause of pathogenic diseases, but also a major source of other pollutants, including oxygen-demanding waste, plant nutrients, and toxic heavy metals.

Review Questions

1. Approximately 97% of all water on Earth is found in what reservoir?
   A. Oceans
   B. Lakes
   C. Streams
   D. Groundwater
   E. Glaciers and ice caps
2. The majority of freshwater, whether accessible to humans or not, is contained in what reservoir?
   A. Ocean
   B. Lakes
   C. Streams
   D. Groundwater
   E. Glaciers and ice caps
3. You are studying a river and notice that it contains chemical waste. You have thoroughly searched the entire length of the stream and ruled out that the waste is directly entering the stream. Instead, the waste must by entering by one of its many tributary streams. Because these streams empty into the river you are studying, they must be within the same…
   A. Watershed
   B. Irrigation district
   C. Riparian area
   D. Aqueduct
   E. Water zone
4. Adding water to a recharge area would have what practical effect?
   A. Increased amount of groundwater
   B. A more pronounced cone of depression
   C. Depletion of an aquifer
   D. Less infiltration
   E. Greater precipitation
5. With removal of groundwater, which of the following may result?
   A. subsidence
   B. sinkholes
   C. cone of depression
   D. decreased water table

E. All of the above.

6. For individuals living in areas where no freshwater is available, which one of the following would produce water that could be used for drinking?
   A. desalination
   B. groundwater mining
   C. sublimation
   D. transpiration
   E. saltation
7. Three carcinogens are equally harmful at equal concentrations. In a terrible industrial accident, 2 tons of each type of carcinogen were discharged into a river at the same time. The residence times of each pollutant is as follows: Chemical X = 2.8 days; Chemical Y = 3.5 days; Chemical Z = 17.2 hours. Which one possesses the greatest risk of exposure to the nearby community over the course of a week following the spill?
   A. Chemical X
   B. Chemical Y
   C. Chemical Z
   D. All chemicals provided equal likelihood of exposure
8. Fertilizers applied to residential lawns and gardens can end up in water bodies through the process of surface run-off or movement through ground water. This type of pollution would be considered…
   A. Point source
   B. Bioremediation
   C. Non-point source
   D. Throughput sourcing
   E. Tangential
9. Which one of the following would most directly prevent a dead zone from forming in a water body that is already experiencing eutrophication?
   A. Increase the O2 concentration in the water
   B. Lower the nutrient levels
   C. Increase the amount of algae and phytoplankton
   D. Increase the amount of bacteria that decompose dead organic matter
   E. Make the water more hypoxic
10. If you analyzed waste water directly after primary treatment, what would you notice?
    A. Harmful bacteria and other biological agents have been killed or removed
    B. The water is potable
    C. Much of the dissolved solids have been removed
    D. Many suspended solids have been removed
    E. The water is mostly sludge

See Appendix for answers

Attributions

Theis, T. & Tomkin, J. (Eds.). (2015). *Sustainability: A comprehensive foundation*. Retrieved from http://cnx.org/contents/1741effd-9cda-4b2b-a91e-003e6f587263@43.5. Available under Creative Commons Attribution 4.0 International License. (CC BY 4.0). Modified from original.

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CHAPTER OVERVIEW

10: Food and Hunger

Learning Outcomes

- Understand the major drivers of food insecurity
- Recognize the role of women in food and nutritional security
- Classify key food and nutritional sources
- Identify benefits and risks of genetic engineering

Page 10.1: Food Security
Page 10.2: Biotechnology and Genetic Engineering
Page 10.3: Chapter Resources

Thumbnail image - By learning skills like composting, crop diversification, organic pesticide production, seed multiplication and agro-forestry farmers in Malawi are increasing their ability to feed their families over the long term.

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Page 10.1: Food Security

Progress continues in the fight against hunger, yet an unacceptably large number of people lack the food they need for an active and healthy life. The latest available estimates indicate that about 795 million people in the world – just over one in nine –still go to bed hungry every night, and an even greater number live in poverty (defined as living on less than $1.25 per day). Poverty—not food availability—is the major driver of food insecurity. Improvements in agricultural productivity are necessary to increase rural household incomes and access to available food but are insufficient to ensure food security. Evidence indicates that poverty reduction and food security do not necessarily move in tandem. The main problem is lack of economic (social and physical) access to food at national and household levels and inadequate nutrition (or hidden hunger). Food security not only requires an adequate supply of food but also entails availability, access, and utilization by all—people of all ages, gender, ethnicity, religion, and socioeconomic levels.

From Agriculture to Food Security

Agriculture and food security are inextricably linked. The agricultural sector in each country is dependent on the available natural resources, as well as the politics that govern those resources. **Staple food crops** are the main source of dietary energy in the human diet and include things such as rice, wheat, sweet potatoes, maize, and cassava.

Food security

Food security is essentially built on four pillars: **availability**, **access**, **utilization** and **stability**. An individual must have access to sufficient food of the right dietary mix (quality) at all times to be food secure. Those who never have sufficient quality food are **chronically food insecure**.

When food security is analyzed at the national level, an understanding not only of national production is important, but also of the country's **access** to food from the global market, its foreign exchange earnings, and its citizens' consumer choices. Food security analyzed at the household level is conditioned by a household's own food production and household members' ability to purchase food of the right quality and diversity in the market place. However, it is only at the individual level that the analysis can be truly accurate because only through understanding who consumes what can we appreciate the impact of sociocultural and gender inequalities on people's ability to meet their nutritional needs.The definition of food security is often applied at varying levels of aggregation, despite its articulation at the individual level. The importance of a pillar depends on the level of aggregation being addressed. At a global level, the important pillar is food**availability**. Does global agricultural activity produce sufficient food to feed all the world's inhabitants? The answer today is yes, but it may not be true in the future given the impact of a growing world population, emerging plant and animal pests and diseases, declining soil productivity and environmental quality, increasing use of land for fuel rather than food, and lack of attention to agricultural research and development, among other factors.

The third pillar, food **utilization**, essentially translates the food available to a household into nutritional security for its members. One aspect of utilization is analyzed in terms of distribution according to need. Nutritional standards exist for the actual nutritional needs of men, women, boys, and girls of different ages and life phases (that is, pregnant women), but these "needs" are often socially constructed based on culture. For example, in South Asia evidence shows that women eat after everyone else has eaten and are less likely than men in the same household to consume preferred foods such as meats and fish. **Hidden hunger** commonly results from poor food utilization: that is, a person's diet lacks the appropriate balance of macro- (calories) and micronutrients (vitamins and minerals). Individuals may look well nourished and consume sufficient calories but be deficient in key micronutrients such as vitamin A, iron, and iodine.

When food security is analyzed at the national level, an understanding not only of national production is important, but also of the country's access to food from the global market, its foreign exchange earnings, and its citizens' consumer choices. Food security analyzed at the household level is conditioned by a household's own food production and household members' ability to purchase food of the right quality and diversity in the market place. However, it is only at the individual level that the analysis can be truly accurate because only through understanding who consumes what can we appreciate the impact of sociocultural and gender inequalities on people's ability to meet their nutritional needs.

Food **stability** is when a population, household, or individual has access to food at all times and does not risk losing access as a consequence of cyclical events, such as the dry season**.** When some lacks food stability, they have **malnutrition,** a lack of essential

nutrients. This is economically costly because it can cost individuals 10 percent of their lifetime earnings and nations 2 to 3 percent of gross domestic product (GDP) in the worst-affected countries (Alderman 2005). Achieving food security is even more challenging in the context of HIV and AIDS. HIV affects people's physical ability to produce and use food, reallocating household labor, increasing the work burden on women, and preventing widows and children from inheriting land and productive resources.

Obesity

Obesity means having too much body fat. It is not the same as overweight, which means weighing too much. Obesity has become a significant global health challenge, yet is preventable and reversible. Over the past 20 years, a global overweight/obesity epidemic has emerged, initially in industrial countries and now increasingly in low- and middle-income countries, particularly in urban settings, resulting in a triple burden of undernutrition, micronutrient deficiency, and overweight/obesity. There is significant variation by region; some have very high rates of undernourishment and low rates of obesity, while in other regions the opposite is true (Figure NaN.1.1).

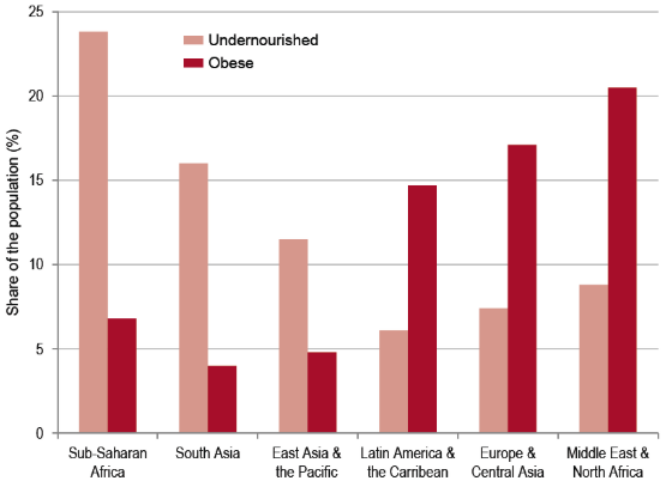


Figure NaN.1.1. Obesity and undernourishment by region.

However, obesity has increased to the extent that the number of overweight people now exceeds the number of underweight people worldwide. The economic cost of obesity has been estimated at $2 trillion, accounting for about 5% of deaths worldwide. Almost 30% of the world's population, or 2.1 billion people, are overweight or obese, 62% of whom live in developing countries.

Obesity accounts for a growing level and share of worldwide noncommunicable diseases, including diabetes, heart disease, and certain cancers that can reduce quality of life and increase public health costs of already under-resourced developing countries. The number of overweight children is projected to double by 2030. Driven primarily by increasing availability of processed, affordable, and effectively marketed food, the global food system is falling short with rising obesity and related poor health outcomes. Due to established health implications and rapid increase in prevalence, obesity is now a recognized major global health challenge.

Suggested Supplementary Reading:

McMillan, T. 2018. How China Plans to Feed 1.4 Billion Growing Appetites. *National Geographic*. February.

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Page 10.2: Biotechnology and Genetic Engineering

In the early 1990s, an emerging disease was destroying Hawaii's production of papaya and threatening to decimate the $11 million industry (Figure $NaN.2.1$). Fortunately, a man named Dennis Gonsalves, who was raised on a sugar plantation and then became a plant physiologist at Cornell University, would develop papaya plants genetically engineered to resist the deadly virus. By the end of the decade, the Hawaiian papaya industry and the livelihoods of many farmers were saved thanks to the free distribution of Dr. Gonsalves seeds.

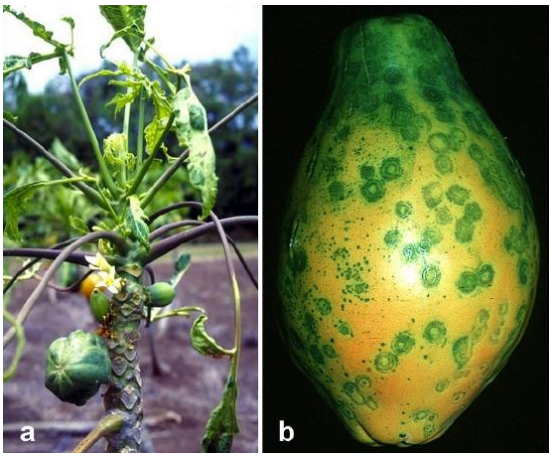


Figure $NaN.2.1$. The symptoms of papaya ringspot virus are shown on the tree (a) and fruit (b). *"This work" is in the Public Domain, CC0.*

The development of a new strain of crop is an example of **agricultural biotechnology:** a range of tools that include both traditional breeding techniques and more modern lab-based methods. Traditional methods date back thousands of years, whereas biotechnology uses the tools of genetic engineering developed over the last few decades. **Genetic engineering** is the name for the methods that scientists use to introduce new traits to an organism. This process results in **genetically modified organisms,** or **GMO**. For example, plants may be genetically engineered to produce characteristics to enhance the growth or nutritional profile of food crops. GMO that are crop species are commonly called **genetically engineered crops**, or **GE crops** for short

The History of Genetic Modification of Crops

Nearly all the fruits and vegetables found in your local market would not occur naturally. In fact, they exist only because of human intervention that began thousands of years ago. Humans created the vast majority of crop species by using traditional breeding practices on naturally-occurring, wild plants. These practices rely upon **selective breeding** (human assisted-breeding of individuals with desirable traits). Traditional breeding practices, although low-tech and simple to perform, have the practical outcome of modifying an organism's genetic information, thus producing new traits.

An interesting example is maize (corn). Biologists have discovered that maize was developed from a wild plant called teosinte. Through traditional breeding practices, humans living thousands of years ago in what is now Southern Mexico began selecting for desirable traits until they were able to transform the plant into what is now known as maize. In doing so, they permanently (and unknowingly) altered its genetic instructions, allowing for new traits to emerge. Considering this history, we might ask the question: is there really such a thing as "non-GMO" maize?

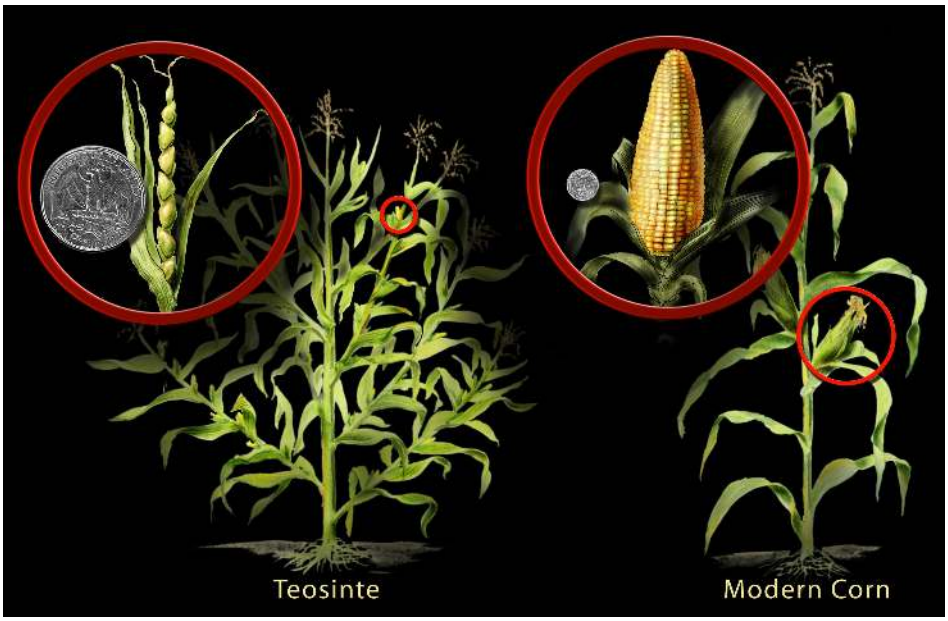


Figure $NaN.2.2$. A wild grass called teosinte was genetically modified through selective breeding to produce what is now known as maize (corn). This process of transformation started thousands of years ago by indigenous people of what is now Mexico. *"This work" by Nicolle Rager Fuller, National Science Foundation is in the Public Domain, CC0.*

This history of genetic modification is common to nearly all crop species. For example, cabbage, broccoli, Brussel sprouts, cauliflower, and kale were all developed from a single species of wild mustard plant (Figure $NaN.2.2$). Wild nightshade was the source of tomatoes, eggplant, tobacco, and potatoes, the latter developed by humans 7,000 – 10,000 years ago in South America.


Figure $NaN.2.3$. Brassica oleracea is a plant in the mustard family and is known as wild cabbage. From it were developed many familar crops, such as cauliflower, broccoli, Brussel sprouts, and of course, cabbage. *"Brassica oleracea wild" by Kulac is licensed under CC BY-SA 4.0*

Traditional Breeding v. Modern Genetic Engineering

To produce new traits in livestock, pets, crops, or other type of organism, there almost always has to be an underlying change in that organism's genetic instructions. What many people might not understand is that traditional breeding practices do, in fact, result in permanent genetic changes and is therefore a type of genetic modification. This misunderstanding may arise because traditional breeding practices do not require sophisticated laboratory equipment or any knowledge of genetics, which some may see as a perquisite for genetic modification.

How do traditional breeding practices compare to modern genetic engineering? Both result in changes to an organism's genetic information, but the magnitude of those changes varies amongst the two techniques (Figure $NaN.2.3$). Traditional breeding shuffles

all of the genes between the two organisms being bred, which can number into the tens of thousands (maize, for example, has 32,000 genes). When mixing such a large number of genes, the results can be unpredictable. Modern genetic engineering is more precise in the sense that biologists can modify just a single gene. Also, genetic engineering can introduce a gene between two distantly-related species, such as inserting a bacterial gene into a plant. Such transfer might seem unusual, but it is not without its equivalent in nature. In a process called **horizontal gene transfer**, DNA from one species can be inserted into a different species. One recent study, for example, has found that humans contain about 150 genes from other species, including bacteria.

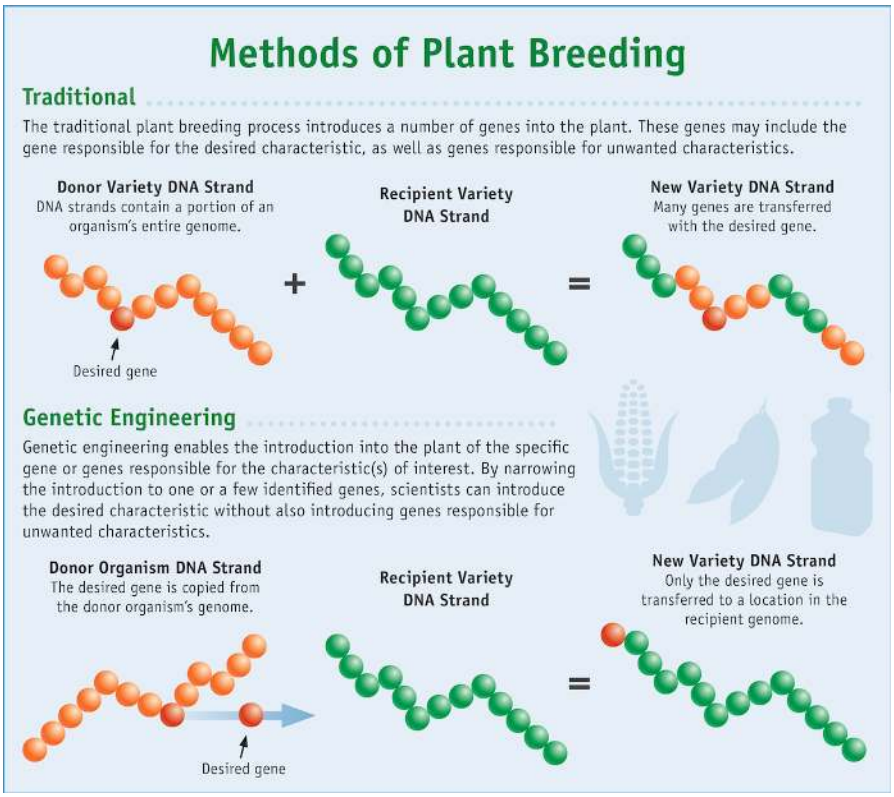


Figure $NaN.2.4$. Both traditional breeding and modern genetic engineering produce genetic modifications. Genetic engineering allows for fewer and more precise genetic modifications. FDA graphic by Michael J. Ermarth (Methods of Plant Breeding) [CC0 Public Domain], via Wikimedia Commons.

Potential Benefits of Genetic Engineering

Enhanced nutrition

Advances in biotechnology may provide consumers with foods that are nutritionally-enriched (Figure $NaN.2.4$), longer-lasting, or that contain lower levels of certain naturally occurring toxins present in some food plants. For example, developers are using biotechnology to try to reduce saturated fats in cooking oils, reduce allergens in foods, and increase disease-fighting nutrients in foods. Biotechnology may also be used to conserve natural resources, enable animals to more effectively use nutrients present in feed, decrease nutrient runoff into rivers and bays, and help meet the increasing world food and land demands.



Figure $NaN.2.5$. White rice and Golden rice. Genetically engineered “Golden Rice” contains up to 35 µg β-carotene per gram of rice, which could prevent millions of cases of blindness worldwide.

Cheaper and More Manageable Production

Biotechnology may provide farmers with tools that can make production cheaper and more manageable. For example, some biotechnology crops can be engineered to tolerate specific herbicides, which make weed control simpler and more efficient. Other crops have been engineered to be resistant to specific plant diseases and insect pests, which can make pest control more reliable and effective, and/or can decrease the use of synthetic pesticides. These crop production options can help countries keep pace with demands for food while reducing production costs.

Improved pest control

Biotechnology has helped to make both pest control and weed management safer and easier while safeguarding crops against disease. For example, genetically engineered insect-resistant cotton has allowed for a significant reduction in the use of persistent, synthetic pesticides that may contaminate groundwater and the environment. In terms of improved weed control, herbicide-tolerant soybeans, cotton, and corn enable the use of reduced-risk herbicides that break down more quickly in soil and are non-toxic to wildlife and humans.



Figure $NaN.2.6$. Worldwide, GE crops account for 12% of all agricultural production in 2015. Shown here are GE crops by nation. *“This work” by NASEM is in the Public Domain, CC0.*

Potential Concerns about Genetically Engineered Crops

The complexity of ecological systems presents considerable challenges for experiments that assess the risks and benefits of GE crops. Assessing such risks is difficult, because both natural and human-modified systems are highly complex and fraught with

uncertainties that may not be clarified until long after an experimental introduction has been concluded. Critics of GE crops warn that their cultivation should be carefully considered within broader ecosystems because of their potential benefits and hazards to the environment.

In addition to environmental risks, some people are concerned about potential health risks of GE crops because they feel that genetic modification alters the intrinsic properties, or essence, of an organism. As discussed above, however, it is known that both traditional breeding practices and modern genetic engineering produce permanent genetic modifications. Further, traditional breeding practices actually have a larger and more unpredictable impact on a species' genetics because of its comparably crude nature. Considering this, it is wise that both new GE crops and traditionally produced crops should be studied for potential human health risks.

To address these various concerns, the US National Academies of Sciences, Engineering, and Medicine (NASEM) published a comprehensive, 500-page report in 2016 that summarized the current scientific knowledge regarding GE crops. The report, titled *Genetically Engineered Crops: Experiences and Prospects*, reviewed more than 900 research articles, in addition to public comments and expert testimony. Results from this seminal report, hereafter referred to as the "**GE Crop Report**" for brevity, is shared in the various subsections below.

Interbreeding with Native Species

Through interbreeding, or hybridization, GE crops might share their genetically-modified DNA with wild relatives. This could affect the genetics of those wild relatives and have unforeseen consequences on their populations, and could even have implications for the larger ecosystem. For example, if a gene engineered to confer herbicide resistance were to pass from a GE crop to a wild relative, it might transform the wild species into a '**super weed'** – a species that could not be controlled by herbicide. Its rampant growth could then displace other wild species and the wildlife that depends on it, thus inflecting ecological harm.

NASEM's GE Crop Report did find some evidence of genetic transfer between GE crops and wild relatives. However, there was no evidence of ecological harm from that transfer. Clearly, continued monitoring, especially for newly-developed crops, is warranted.

Consumers Right to Choose

The International Federation of Organic Agriculture Movement has made stringent efforts to keep GE crops out of organic production, yet some US organic farmers have found their corn (maize) crops, including seeds, contain detectable levels of genetically engineered DNA. The organic movement is firm in its opposition to any use of GE crops in agriculture, and organic standards explicitly prohibit their use (however, keep in mind that even "organic" maize has incurred significant genetic modification compared to its wild relative, teosinte). The farmers, whose seed is contaminated, have been under rigid organic certification, which assures that they did not use any kind of genetically modified materials on their farms.

Any trace of GE crops must have come from outside their production areas. While the exact origin is unclear at this time, it is likely that the contamination has been caused by pollen drift from GE crop fields in surrounding areas. However, the contamination may have also come from the seed supply. Seed producers, who intended to supply GE crop-free seed, have also been confronted with genetic contamination and cannot guarantee that their seed is 100% GE crop-free.

Long-Term Ecological Effects

An early study indicated the pollen from a particular type of genetically modified corn may be harmful to the caterpillars of monarch butterflies, This type of corn, known as ***Bt* corn,** is genetically modified to produce a bacterial protein that acts as an insecticide. This trait is favorable because it reduces the amount of insecticides used by farmers. Pollen from *Bt* corn can be harmful to caterpillars, but only at very high concentrations. These concentrations are seldom reached in nature and follow-up studies have found the effect of *Bt* corn to be negligible.

NASEM's GE Crop Report documents that the validity of that initial monarch study was questioned by other scientists and this ultimately led to a large, multi-national study funded by the US and Canada. They found that the vast majority of *Bt* corn grown did not represent a risk to monarchs. However, one strain of *Bt* corn did, and it was consequently removed from the market.

The GE Crop Report also mentioned a separate threat to monarch: loss of milkweed, which is critical to the butterfly's lifecycle. Some GE crops are engineered to resist the herbicide glyphosate. Farmers using these crops can spray their entire field with the herbicide, which kills milkweed but not their GE crop. This can lower the amount of milkweed growing within the habitat range of

monarchs. The report concluded that more studies are needed to quantify the actual impact this may be having on monarch populations.

Human Health Risk

At least some of the genes used in GE crops may not have been used in the food supply before, so GM foods may pose a potential risk for human health, such as producing new allergens. But this is also true of crops generated by traditional breeding practices (because both produce genetic modifications and thus new traits).

Like other 'controversial' scientific issues, the scientific consensus on GE crops is quite clear: they are safe. The UN's Food and Agriculture Organization has concluded that risks to human and animal health from the use of GMOs are negligible. NASEM's GE Crop Report found "no substantiated evidence of a difference in risks to human health between current commercially available genetically engineered (GE) crops and conventionally bred crops, nor did it find conclusive cause-and-effect evidence of environmental problems from the GE crops." The American Medical Association's Council on Science and Public Health, in 2012, stated that "Bioengineered foods have been consumed for close to 20 years, and during that time, no overt consequences on human health have been reported and/or substantiated in the peer-reviewed literature." Similar statements have been made by the US National Resource Council and the American Association for the Advancement of Science, which publishes the preeminent scholarly journal, *Science*.

The potential of GE crops to be allergenic is one of the potential adverse health effects and it should continue to be studied, especially because some scientific evidences indicates that animals fed GE crops have been harmed. NASEM's GE Crop Report concluded that when developing new crops, it is the product that should be studied for potential health and environmental risks, not the process that achieved that product. What this means is, because both traditional breeding practices and modern genetic engineering produce new traits through genetic modification, they both present potential risks. Thus, for the safety of the environment and human health, both should be adequately studied.

Intellectual Property Rights

Intellectual property rights are one of the important factors in the current debate on GE crops. GE crops can be patented by Agri-businesses, which can lead to them controlling and potentially exploiting agricultural markets. Some accuse companies, such as Monsanto, of allegedly controlling seed production and pricing, much to the detriment of farmers. NASEM's GE Crop Report recommends more research into how the concentration of seed-markets by a few companies, and the subsequent reduction of free market competition, may be affecting seed prices and farmers.

It should be noted that crops developed by traditional breeding can also be legally protected and controlled in ways similar to GE crops. Jim Myers, from Oregon State University notes that "In all but a few cases, all contemporary varieties developed by private breeders are [legally] protected, and most public varieties are protected as well."

Are GE Crops the Solution We Need?

Significant resources, both financial and intellectual, have been allocated to answering the question: are GE crops safe? After many hundreds of scientific studies, the answer is yes. But a significant question still remains: are they necessary? Certainly, such as in instances like Hawaii's papaya, which were threated with eradication due to an aggressive disease, genetic engineering was a quick and effective solution that would have been extremely difficult, if not impossible, to solve using traditional breeding practices.

However, in many cases, the early promises of GE crops – that they would improve nutritional quality of foods, confer disease resistance, and provide unparalleled advances in crop yields – have largely failed to come to fruition. NASEM's GE Crop Report states that while GE crops have resulted in the reduction of agricultural loss from pests, reduced pesticide use, and reduced rates of injury from insecticides for farm workers, they have not increased the rate at which crop yields are advancing when compared to non-GE crops. Additionally, while there are some notable exceptions like golden rice or virus-resistant papayas, very few GE crops have been produced to increase nutritional capacity or to prevent plant disease that can devastate a farmer's income and reduce food security. The vast majority of GE crops are developed for only two purposes: to introduce herbicide resistance or pest resistance.

Genetic engineering of crops represents in important tool in a world of rapidly changing climate and a burgeoning human population, but as you will see in the next chapter, it is only one of many tools that agriculturists can use to produce enough food

for all humans while simultaneously working to conserve the environment.

Suggested Supplementary Reading:

Achenbach, J. 2015. “Why Do Many Reasonable People Doubt Science?” *National Geographic Magazine*. https://www.nationalgeographic.com/magazine/2015/03/science-doubters-climate-change-vaccinations-gmos/

NASEM. 2016.*Genetically Engineered Crops: Experiences and Prospects*. http://nas-sites.org/ge-crops/category/report/

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Page 10.3: Chapter Resources

Summary

Progress continues in the fight against hunger, yet an unacceptably large number of people still lack the food they need for an active and healthy life. About 795 million people in the world still go to bed hungry every night, and an even greater number live in poverty. Poverty is the major driver of food insecurity. Improvements in agricultural productivity are necessary to increase rural household incomes and access to available food but are insufficient to ensure food security. Food security is essentially built on four pillars: availability, access, utilization and stability. Women are crucial in the translation of the products of a vibrant agriculture sector into food and nutritional security for their households. They are often the farmers who cultivate food crops and produce commercial crops alongside the men in their households as a source of income. Over the past 20 years, a global obesity epidemic has emerged. Due to established health implications and rapid increase in prevalence, obesity is now a recognized major global health challenge, and no national success stories in curbing its growth have so far been reported. Genetic engineering is the name for methods that scientists use to introduce new traits or characteristics to an organism. Advocates say that application of genetic engineering in agriculture has resulted in benefits to farmers, producers, and consumers. Critics advise that the risks for the introduction of a GMO into each new ecosystem need to be examined on a case-by-case basis, alongside appropriate risk management measures.

Review Questions

1. Which one of the following is not one of the four pillars of food security?
   A. Availability
   B. Access
   C. Utilization
   D. Transformation
   E. Stability
2. Which one of the following statements is false regarding selective breeding?
   A. It results in genetic changes in the offspring
   B. It is anthropogenic
   C. Is reliant upon modern, lab-based methods
   D. It can produce new traits over time
   E. It was responsible for creating many common crops, such as maize (corn)
3. The US National Academy of Sciences, Engineering, and Medicine, along with other organizations such as the American Medical Association, have determined that GE crops…
   A. Are safe to consume
   B. Likely pose a risk to human health
   C. Pose a serious risk to human health
   D. Should be banned
   E. Have not been scientifically studied and therefore they cannot make any recommendations.
4. Which one of the following regions has obesity rates that are lower than rates of undernourishment?
   A. Middle East and North Africa
   B. Latin America and Caribbean
   C. Europe and Central Asia
   D. South Asia
5. Potatoes, tomatoes, and tobacco were are developed by humans many thousands of years ago by the genetic modification of wild nightshade species. Specifically, these crops were developed using…
   A. Selective breeding
   B. Horizontal gene transfer
   C. Epigenetics
   D. Natural selection

E. Anthropogenesis

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

11: Conventional and Sustainable Agriculture

Learning Outcomes

- Describe the components of soils
- Discuss how land use affects global ecosystem conditions
- Identify environmental effects of pesticides
- Recognize the relationship between exposure to POPs and human health
- Explain alternative practices in farming and soil management

Page 11.1: Soil Profiles and Processes

Page 11.2: Soil-Plant Interactions

Page 11.3: Conventional Agriculture

Page 11.4: Pests and Pesticides

Page 11.5: Sustainable Agriculture

Page 11.S: Conventional and Sustainable Agriculture (Summary)

Thumbnail image - Women farmers planting a rice field in West Sumatra.

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Page 11.1: Soil Profiles and Processes

What is Soil?

The word "**soil**" has been defined differently by different scientific disciplines. In agriculture and horticulture, soil generally refers to the medium for plant growth, typically material within the upper meter or two (Figure $Page 11.1.1$). We will use this definition in this chapter. Soil consists predominantly of mineral matter, but also contains organic matter (**humus**) and living organisms. The pore spaces between mineral grains are filled with varying proportions of water and air.

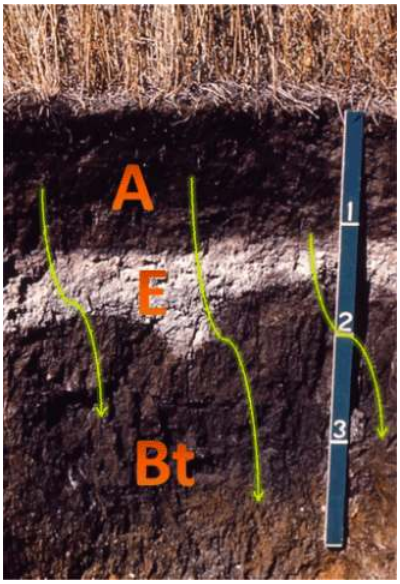


Figure $Page 11.1.1$. Soil Profile. Photograph shows a soil profile from South Dakota with A, E, and Bt horizons. The yellow arrows symbolize translocation of fine clays to the Bt horizon. The scale is in feet. Source: University of Idaho and modified by D. Grimley.

In common usage, the term soil is sometimes restricted to only the dark topsoil in which we plant our seeds or vegetables. In a more broad definition, civil engineers use the term soil for any unconsolidated (soft when wet) material that is not considered bedrock. Under this definition, soil can be as much as several hundred feet thick! Ancient soils, sometimes buried and preserved in the subsurface, are referred to as **paleosols** (Figure $Page 11.1.2$) and reflect past climatic and environmental conditions.

Importance of Soil

Soil is important to our society primarily because it provides the foundation of agriculture and forestry. Of course, soil is also a critical component for terrestrial ecosystems, and thus important to animals, plants, fungi, and microorganisms.

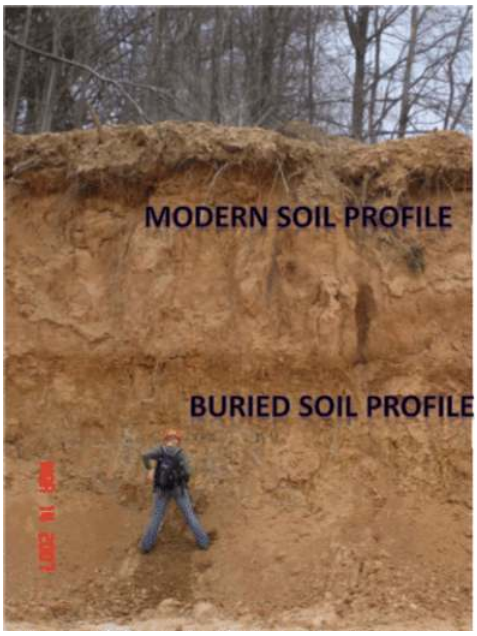


Figure $Page11.1.2$. Modern versus Buried Soil Profiles. A buried soil profile, or paleosol (above geologist ‘s head), represents soil development during the last interglacial period. A modern soil profile (Alfisol) occurs near the land surface. Source: D. Grimley.

Soil plays a role in nearly all biogeochemical cycles on the Earth’s surface. Global cycling of key elements such as carbon (C), nitrogen (N), sulfur (S), and phosphorous (P) all pass through soil. In the hydrologic cycle, soil helps to mediate the flow of precipitation from the surface into the groundwater. Microorganisms living in soil can also be important components of biogeochemical cycles through the action of decomposition and other processes such as nitrogen fixation.

Soil Forming Factors

The fundamental factors that affect soil genesis can be categorized into five elements: climate, organisms, relief, parent material, and time. One could say that the relief, climate, and organisms dictate the local soil environment and act together to cause weathering and mixing of the soil parent material over time. As soil is formed it often has distinct layers, which are formally described as “horizons.” Upper horizons (labeled as the A and O horizons) are richer in organic material and so are important in plant growth, while deeper layers (such as the B and C horizons) retain more of the original features of the bedrock below (Figure $Page11.1.3$).

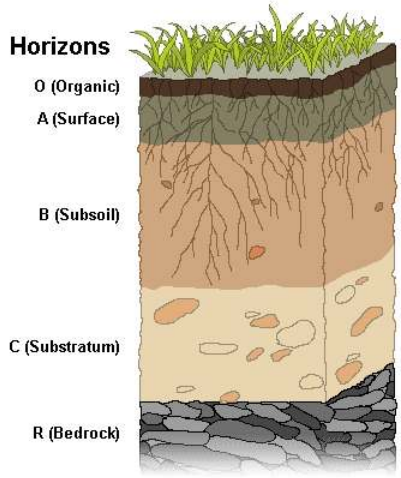


Figure $Page11.1.3$. This images shows the different horizons, or layers, in soil. *This work by Wilsonbiggs is licensed under CC BY-SA 4.0*

Climate

The role of climate in soil development includes aspects of temperature and precipitation. Soils in very cold areas with permafrost conditions tend to be shallow and weakly developed due to the short growing season. Organic rich surface horizons are common in low-lying areas due to limited decomposition. In warm, tropical soils, soils tend to be thicker, with extensive leaching and mineral alteration. In such climates, organic matter decomposition and chemical weathering occur at an accelerated rate.

Organisms

Animals, plants, and microorganisms all have important roles in soil development processes, in providing a supply of organic matter, and/or in nutrient cycling. Worms, nematodes, termites, ants, gophers, moles, etc. all cause considerable mixing of soil and help to blend soil, aerate and lighten the soil by creating pores (which help store water and air).

Plant life provides organic matter to soil and helps to recycle nutrients with uptake by roots in the subsurface. The type of plant life that occurs in a given area, such as types of trees or grasses, depends on the climate, along with parent material and soil type. With the annual dropping of leaves and needles, trees tend to add organic matter to soil surfaces, helping to create a thin, organic-rich A or O horizon over time. Grasses, on the other hand, have a considerable root and surface masses that add to the soil each fall for annuals and short-lived perennials. For this reason, grassland soils have much thicker A horizons with higher organic matter contents, and are more agriculturally productive than forest soils.

Relief (Topography and Drainage)

The local landscape can have a surprisingly strong effect on the soils that form on site. The local topography (**relief**) can have important microclimatic effects as well as affecting rates of soil erosion. In comparison to flat regions, areas with steep slopes overall have more soil erosion, more runoff of rainwater, and less water infiltration, all of which lead to more limited soil development in very hilly or mountainous areas. In the northern hemisphere, south-facing slopes are exposed to more direct sunlight angles and are thus warmer and drier than north-facing slopes. The cooler, moister north-facing slopes have a more dynamic plant community due to less evapotranspiration and, consequently, experience less erosion because of plant rooting of soil and have thicker soil development.

Soil drainage affects organic matter accumulation and preservation, and local vegetation types. Well-drained soils, generally on hills or sideslopes, are more brownish or reddish due to conversion of ferrous iron (Fe^{2+}) to minerals with ferric (Fe^{3+}) iron. More poorly drained soils, in lowland, alluvial plains or upland depressions, tend more be more greyish, greenish-grey (gleyed), or dark colored, due to iron reduction (to Fe^{2+}) and accumulation and preservation of organic matter in areas tending towards anoxic. Areas with poor drainage also tend to be lowlands into which soil material may wash and accumulate from surrounding uplands, often resulting in overthickened A or O horizons. In contrast, steeply sloping areas in highlands may experience erosion and have thinner surface horizons.

Parent Material

The **parent material** of a soil is the material from which the soil has developed, whether it be river sands, shoreline deposits, glacial deposits, or various types of bedrock. In youthful soils, the parent material has a clear connection to the soil type and has significant influence. Over time, as weathering processes deepen, mix, and alter the soil, the parent material becomes less recognizable as chemical, physical, and biological processes take their effect. The type of parent material may also affect the rapidity of soil development. Parent materials that are highly weatherable (such as volcanic ash) will transform more quickly into highly developed soils, whereas parent materials that are quartz-rich, for example, will take longer to develop. Parent materials also provide nutrients to plants and can affect soil internal drainage (e.g. clay is more impermeable than sand and impedes drainage).

Time

In general, soil profiles tend to become thicker (deeper), more developed, and more altered over time. However, the rate of change is greater for soils in youthful stages of development. The degree of soil alteration and deepening slows with time and at some point, after tens or hundreds of thousands of years, may approach an equilibrium condition where erosion and deepening (removals and additions) become balanced. **Young soils** (< 10,000 years old) are strongly influenced by parent material and typically develop horizons and character rapidly. **Moderate age soils** (roughly 10,000 to 500,000 years old) are slowing in profile development and

deepening, and may begin to approach equilibrium conditions. **Old soils** (>500,000 years old) have generally reached their limit as far as soil horizonation and physical structure, but may continue to alter chemically or mineralogically.

Soil development is not always continual. Geologic events can rapidly bury soils (landslides, glacier advance, lake transgression), can cause removal or truncation of soils (rivers, shorelines) or can cause soil renewal with additions of slowly deposited sediment that add to the soil (wind or floodplain deposits). Biological mixing can sometimes cause soil regression, a reversal or bump in the road for the normal path of increasing development over time.

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Page 11.2: Soil-Plant Interactions

Soil plays a key role in plant growth. Beneficial aspects to plants include providing physical support, water, heat, nutrients, and oxygen (Figure $Page 11.2.1$). Mineral nutrients from the soil can dissolve in water and then become available to plants. Although many aspects of soil are beneficial to plants, excessively high levels of trace metals (either naturally occurring or anthropogenically added) or applied herbicides can be toxic to some plants.

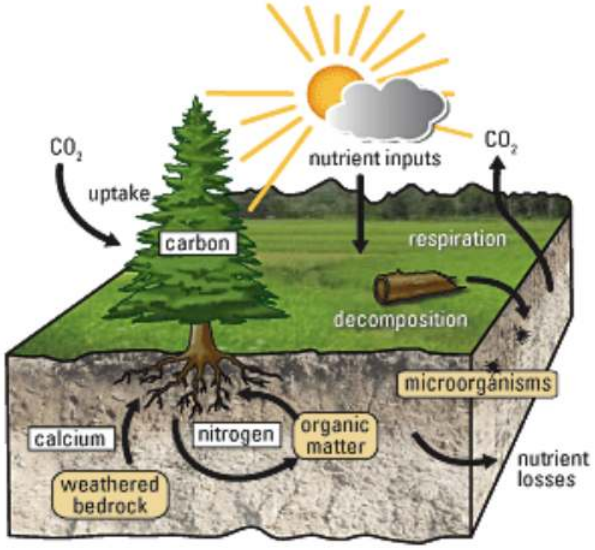


Figure $Page 11.2.1$. Soil-Plant Nutrient Cycle. This figure illustrates the uptake of nutrients by plants in the forest-soil ecosystem. Source: U.S. Geological Survey.

The ratio of solids/water/air in soil is also critically important to plants for proper oxygenation levels and water availability. Too much porosity with air space, such as in sandy or gravelly soils, can lead to less available water to plants, especially during dry seasons when the water table is low. Too much water, in poorly drained regions, can lead to anoxic conditions in the soil, which may be toxic to some plants.

Nutrient Uptake by Plants

Several elements obtained from soil are considered essential for plant growth. **Macronutrients**, including C, H, O, N, P, K, Ca, Mg, and S, are needed by plants in significant quantities. C, H, and O are mainly obtained from the atmosphere or from rainwater. These three elements are the main components of most organic compounds, such as proteins, lipids, carbohydrates, and nucleic acids. The other six elements (N, P, K, Ca, Mg, and S) are obtained by plant roots from the soil and are variously used for protein synthesis, chlorophyll synthesis, energy transfer, cell division, enzyme reactions, and **homeostasis** (the process regulating the conditions within an organism).

Micronutrients are essential elements that are needed only in small quantities, but can still be limiting to plant growth since these nutrients are not so abundant in nature. Micronutrients include iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), zinc (Zn), and copper (Cu). There are some other elements that tend to aid plant growth but are not absolutely essential.

Micronutrients and macronutrients are desirable in particular concentrations and can be detrimental to plant growth when concentrations in soil solution are either too low (limiting) or too high (toxicity). Mineral nutrients are useful to plants only if they are in an extractable form in soil solutions, such as a dissolved ion rather than in solid mineral. Many nutrients move through the soil and into the root system as a result of concentration gradients, moving by diffusion from high to low concentrations. However, some nutrients are selectively absorbed by the root membranes, enabling concentrations to become higher inside the plant than in the soil.

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Page 11.3: Conventional Agriculture

The prevailing agricultural system, variously called "**conventional farming**," "modern agriculture," or "industrial farming," has delivered tremendous gains in productivity and efficiency. Food production worldwide has risen in the past 50 years; the World Bank estimates that between 70 percent and 90 percent of the recent increases in food production are the result of conventional agriculture rather than greater acreage under cultivation. U.S. consumers have come to expect abundant and inexpensive food.



Figure $Page$11.3.1. Conventional agriculture is dependent on large investments in mechanized equipment powered mostly by fossil fuels. This has made agriculture efficient, but has had an impact on the environment. *Cotton Harvest byKimberly Vardeman is licensed under CC BY 4.0.*

Conventional farming systems vary from farm to farm and from country to country. However, they share many characteristics such as rapid technological innovation, large capital investments in equipment and technology, large-scale farms, single crops (**monocultures**); uniform high-yield hybrid crops, dependency on agribusiness, mechanization of farm work, and extensive use of pesticides, fertilizers, and herbicides. In the case of livestock, most production comes from systems where animals are highly concentrated and confined.

Both positive and negative consequences have come with the bounty associated with industrial farming. Some concerns about conventional agriculture are presented below.

Ecological Concerns

Agriculture profoundly affects many ecological systems. Negative effects of current practices include the following:

Decline in soil productivity can be due to wind and water erosion of exposed topsoil, soil compaction, loss of soil organic matter, water holding capacity, and biological activity; and **salinization** (increased salinity) of soils in highly-irrigated farming areas. Converting land to desert (**desertification)** can be caused by overgrazing of livestock and is a growing problem, especially in parts of Africa.

Agricultural practices have been found to contribute to non-point source water pollutants that include salts, fertilizers (nitrates and phosphorus, especially), pesticides, and herbicides. Pesticides from every chemical class have been detected in groundwater and are commonly found in groundwater beneath agricultural areas. They are also widespread in the nation's surface waters. Eutrophication and "dead zones" due to nutrient runoff affect many rivers, lakes, and oceans. Reduced water quality impacts agricultural production, drinking water supplies, and fishery production. Water scarcity (discussed in the previous chapter) in many places is

due to overuse of surface and ground water for irrigation with little concern for the natural cycle that maintains stable water availability.

Other environmental ills include over 400 insects and mite pests and more than 70 fungal pathogens that have become resistant to one or more pesticides. Pesticides have also placed stresses on pollinators and other beneficial insect species. This, along with habitat loss due to converting wildlands into agricultural fields, has affected entire ecosystems (such as the practice of converting tropical rainforests into grasslands for raising cattle).

Agriculture's link to global climate change is just beginning to be appreciated. Destruction of tropical forests and other native vegetation for agricultural production has a role in elevated levels of carbon dioxide and other greenhouse gases. Recent studies have found that soils may be large reservoirs of carbon.

Economic and Social Concerns

Economically, the U.S. agricultural sector includes a history of increasingly large federal expenditures. Also observed is a widening disparity among the income of farmers and the escalating concentration of **agribusiness**—industries involved with manufacture, processing, and distribution of farm products—into fewer and fewer hands. Market competition is limited and farmers have little control over prices of their goods, and they continue to receive a smaller and smaller portion of consumer dollars spent on agricultural products.

Economic pressures have led to a tremendous loss to the number of farms, particularly small farms, and farmers during the past few decades. More than 155,000 farms were lost from 1987 to 1997. Economically, it is very difficult for potential farmers to enter the business today because of the high cost of doing business. Productive farmland also has been swallowed up by urban and suburban sprawl—since 1970, over 30 million acres have been lost to development.

Impacts on Human Health

Many potential health hazards are tied to farming practices. The general public may be affected by the sub-therapeutic use of antibiotics in animal production and the contamination of food and water by pesticides and nitrates. These are areas of active research to determine the levels of risk. The health of farm workers is also of concern, as their risk of exposure is much higher.

Philosophical Considerations

Historically, farming played an important role in our development and identity as a nation. From strongly agrarian roots, we have evolved into a culture with few farmers. Less than two percent of Americans now produce food for all U.S. citizens. Can sustainable and equitable food production be established when most consumers have so little connection to the natural processes that produce their food? What intrinsically American values have changed and will change with the decline of rural life and farmland ownership?

World population continues to grow. According to recent United Nations population projections, the world population will grow to 9.7 billion in 2050 and 11.2 billion in 2100. The rate of population increase is especially high in many developing countries. In these countries, the population factor, combined with rapid industrialization, poverty, political instability, and large food imports and debt burden, make long-term food security especially urgent.

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Page 11.4: Pests and Pesticides

Pests are organisms that occur where they are not wanted or that cause damage to crops or humans or other animals. Thus, the term "pest" is a highly subjective term. A **pesticide** is a term for any substance intended for preventing, destroying, repelling, or mitigating any pest. Though often misunderstood to refer only to insecticides, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests. By their very nature, most pesticides create some risk of harm—pesticides can cause harm to humans, animals, and/or the environment because they are designed to kill or otherwise adversely affect living things. At the same time, pesticides are useful to society because they can kill potential disease-causing organisms and control insects, weeds, worms, and fungi.



Figure $Page11.4.1$. The cotton boll weevil is considered a major pest because of the damage it does to cotton plants. *This work by Jimmy Smith is licensed under CC BY-NC-ND 4.0.*

Pest Control is a Common Tool

The management of pests is an essential part of agriculture, public health, and maintenance of power lines and roads. Chemical pest management has helped to reduce losses in agriculture and to limit human exposure to disease vectors, such as mosquitoes, saving many lives. Chemical pesticides can be effective, fast acting, adaptable to all crops and situations. When first applied, pesticides can result in impressive production gains of crops. However, despite these initial gains, excessive use of pesticides can be ecologically unsound, leading to the destruction of natural enemies, the increase of pesticide resistance, and outbreaks of secondary pests.

These consequences have often resulted in higher production costs as well as environmental and human health costs– side-effects which have been unevenly distributed. Despite the fact that the lion's share of chemical pesticides are applied in developed countries, 99 percent of all pesticide poisoning cases occur in developing countries where regulatory, health and education systems are weakest. Many farmers in developing countries overuse pesticides and do not take proper safety precautions because they do not understand the risks and fear smaller harvests. Making matters worse, developing countries seldom have strong regulatory systems for dangerous chemicals; pesticides banned or restricted in industrialized countries are used widely in developing countries. Farmers' perceptions of appropriate pesticide use vary by setting and culture. Prolonged exposure to pesticides has been associated with several chronic and acute health effects like non-Hodgkin's lymphoma, leukemia, as well as cardiopulmonary disorders, neurological and hematological symptoms, and skin diseases.

HUMAN HEALTH, ENVIRONMENTAL, AND ECONOMIC EFFECTS OF PESTICIDE USE IN POTATO PRODUCTION IN ECUADOR

The International Potato Center (CIP) conducted an interdisciplinary and inter-institutional research intervention project dealing with pesticide impacts on agricultural production, human health, and the environment in Carchi, Ecuador. Carchi is the most important potato-growing area in Ecuador, where smallholder farmers dominate production. They use tremendous amounts of pesticides for the control of the Andean potato weevil and the late blight fungus. Virtually all farmers apply class 1b highly toxic pesticides using hand pump backpack sprayers.

The study found that the health problems caused by pesticides are severe and are affecting a high percentage of the rural population. Despite the existence of technology and policy solutions, government policies continue to promote the use of pesticides. The study conclusions concurred with those by the pesticide industry, "that any company that could not ensure the safe use of highly toxic pesticides should remove them from the market and that it is almost impossible to achieve safe use of highly toxic pesticides among small farmers in developing countries."

Source: Yanggen et al. 2003.

Persistent Organic Pollutants

Persistent organic pollutants (POPs) are a group of organic chemicals, such as DDT, that have been widely used as pesticides or industrial chemicals and pose risks to human health and ecosystems. POPs have been produced and released into the environment by human activity. They have the following three characteristics:

- **Persistent**: POPs are chemicals that last a long time in the environment. Some may resist breakdown for years and even decades while others could potentially break down into other toxic substances.
- **Bioaccumulative**: POPs can accumulate in animals and humans, usually in fatty tissues and largely from the food they consume. As these compounds move up the food chain, they concentrate to levels that could be thousands of times higher than acceptable limits.
- **Toxic**: POPs can cause a wide range of health effects in humans, wildlife and fish. They have been linked to effects on the nervous system, reproductive and developmental problems, suppression of the immune system, cancer, and endocrine disruption. The deliberate production and use of most POPs has been banned around the world, with some exemptions made for human health considerations (e.g., DDT for malaria control) and/or in very specific cases where alternative chemicals have not been identified. However, the unintended production and/or the current use of some POPs continue to be an issue of global concern. Even though most POPs have not been manufactured or used for decades, they continue to be present in the environment and thus potentially harmful. The same properties that originally made them so effective, particularly their stability, make them difficult to eradicate from the environment.

POPs and Health

The relationship between exposure to environmental contaminants such as POPs and human health is complex. There is mounting evidence that these persistent, bioaccumulative and toxic chemicals (PBTs) cause long-term harm to human health and the environment. Drawing a direct link, however, between exposure to these chemicals and health effects is complicated, particularly since humans are exposed on a daily basis to many different environmental contaminants through the air they breathe, the water they drink, and the food they eat. Numerous studies link POPs with a number of adverse effects in humans. These include effects on the nervous system, problems related to reproduction and development, cancer, and genetic impacts. Moreover, there is mounting public concern over the environmental contaminants that mimic hormones in the human body (**endocrine disruptors**).

As with humans, animals are exposed to POPs in the environment through air, water and food. POPs can remain in sediments for years, where bottom-dwelling creatures consume them and who are then eaten by larger fish. Because tissue concentrations can increase or biomagnify at each level of the food chain, top predators (like largemouth bass or walleye) may have a million times greater concentrations of POPs than the water itself. The animals most exposed to PBT contaminants are those higher up the food web such as marine mammals including whales, seals, polar bears, and birds of prey in addition to fish species such as tuna, swordfish and bass (Figure $Page$11.4.2). Once POPs are released into the environment, they may be transported within a specific region and across international boundaries transferring among air, water, and land.

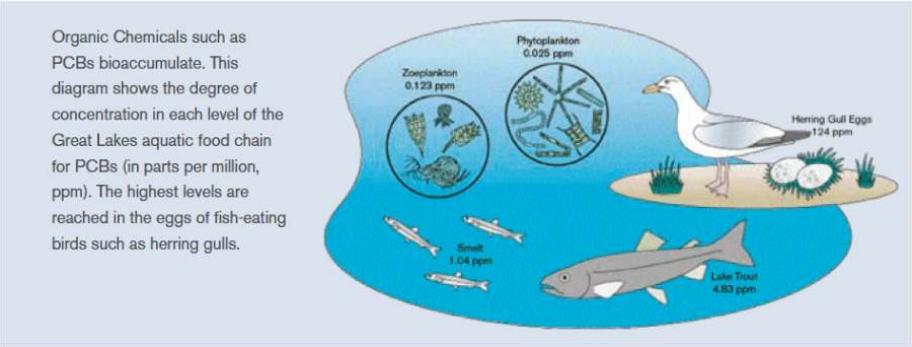


Figure $Page$11.4.2. Bioaccumulation and biomagnification. U.S. EPA. Great Lakes: The Great Lakes Atlas: Chapter Four the Great Lakes Today – Concerns. January 2009

"Grasshopper Effect"

While generally banned or restricted, POPs make their way into and throughout the environment on a daily basis through a cycle of long-range air transport and deposition called the "**grasshopper effect.**"The "grasshopper" processes, illustrated in Figure

$Page$11.4.3, begin with the release of POPs into the environment. When POPs enter the atmosphere, they can be carried with wind currents, sometimes for long distances.

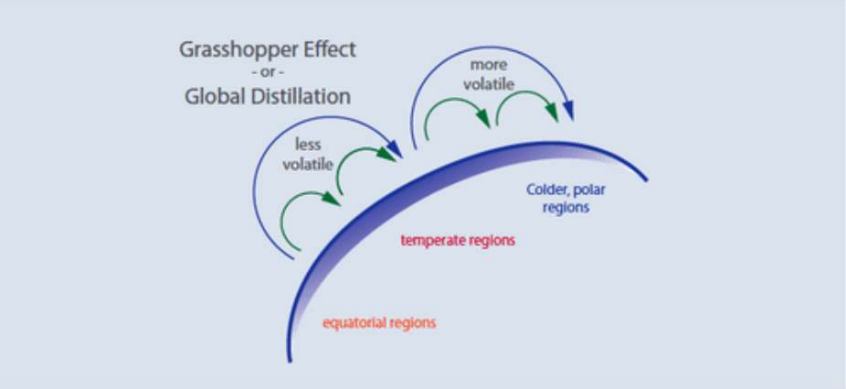


Figure $Page$11.4.3. How POPs move throughout the environment. Source: Environment Canada. The Science and the Environment Bulletin. May/June 1998

Through atmospheric processes, they are deposited onto land or into water ecosystems where they accumulate and potentially cause damage. From these ecosystems, they evaporate, again entering the atmosphere, typically traveling from warmer temperatures toward cooler regions. They condense out of the atmosphere whenever the temperature drops, eventually reaching highest concentrations in circumpolar countries. Through these processes, POPs can move thousands of kilometers from their original source of release in a cycle that may last decades.

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Page 11.5: Sustainable Agriculture

"**Sustainable agriculture**" was addressed by Congress in the 1990 "Farm Bill". Under that law, "the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

Organic Farming is Good for Farmers, Consumers and the Environment

Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. Organic food is produced by farmers who emphasize the use of renewable resources and the conservation of soil and water to enhance environmental quality for future generations. Organic meat, poultry, eggs, and dairy products come from animals that are given no antibiotics or growth hormones. Organic food is produced without using most conventional pesticides, fertilizers made with synthetic ingredients or sewage sludge, or GMOs.

Organic production, with the corresponding practices to maintain soil fertility and soil health is therefore a more benign alternative to conventional, high-value horticulture. The organic food movement has been endorsed by the UN's Food and Agricultural Organization, which maintains in a 2007 report that organic farming fights hunger, tackles climate change, and is good for farmers, consumers, and the environment. The strongest benefits of organic agriculture are its use of resources that are independent of fossil fuels, are locally available, incur minimal environmental stresses, and are cost effective.

IPM is a Combination of Common-Sense Practices

Integrated Pest Management (IPM) refers to a mix of farmer-driven, ecologically-based pest control practices that seeks to reduce reliance on synthetic chemical pesticides. It involves (a) managing pests (keeping them below economically damaging levels) rather than seeking to eradicate them; (b) relying, to the extent possible, on non-chemical measures to keep pest populations low; and (c) selecting and applying pesticides, when they have to be used, in a way that minimizes adverse effects on beneficial organisms, humans, and the environment. It is commonly understood that applying an IPM approach does not necessarily mean eliminating pesticide use, although this is often the case because pesticides are often over-used for a variety of reasons.

The IPM approach regards pesticides as mainly short-term corrective measures when more ecologically based control measures are not working adequately (sometimes referred to as using pesticides as the "last resort"). In those cases when pesticides are used, they should be selected and applied in such a manner as to minimize the amount of disruption that they cause to the environment, such as using products that are non-persistent and applying them in the most targeted way possible).

Biological Control

Biological control (biocontrol) is the use of one biological species to reduce populations of a different species. There has been a substantial increase in commercialization of biocontrol products, such as beneficial insects, cultivated predators and natural or non-toxic pest control products. Biocontrol is being mainstreamed to major agricultural commodities, such as cotton, corn and most commonly vegetable crops. Biocontrol is also slowly emerging in vector control in public health and in areas that for a long time mainly focused on chemical vector control in mosquito/malaria—and black fly/onchocerciasis—control programs. Successful and commercialized examples of biocontrol include ladybugs to depress aphid populations, parasitic wasps to reduce moth populations, use of the bacterium *Bacillus thuringenensis* to kill mosquito and moth larvae, and introduction of fungi, such as Trichoderma, to suppress fungal-caused plant diseases, leaf beetle (*Galerucella calmariensis*) to suppress purple loosestrife, a noxious weed (Figure $Page11.5.1$). In all of these cases, the idea is not to completely destroy the pathogen or pest, but rather to reduce the damage below economically significant values.



Figure $Page11.5.1$. Young larvae of the leaf-beetle feed in and on the developing buds of plants, often destroying them. This may stunt plant growth and delay or prevent flowering. Adults (shown) and older larvae feed on leaves and cause severe defoliation. Leaf-beetles can be used to as a biocontrol for invasive plants such as purple loosestrife.

Intercropping Promotes Plant Interactions

Intercropping means growing two or more crops in close proximity to each other during part or all of their life cycles to promote soil improvement, biodiversity, and pest management. Incorporating intercropping principles into an agricultural operation increases diversity and interaction between plants, arthropods, mammals, birds and microorganisms resulting in a more stable crop-ecosystem and a more efficient use of space, water, sunlight, and nutrients (Figure $Page11.5.2$). This collaborative type of crop management mimics nature and is subject to fewer pest outbreaks, improved nutrient cycling and crop nutrient uptake, and increased water infiltration and moisture retention. Soil quality, water quality and wildlife habitat all benefit.



Figure $Page11.5.2$. Intercropping alyssum (the flowering plants shown center left) with organic romaine lettuce for aphid control.

Organic Farming Practices Reduce Unnecessary Input Use

In modern agricultural practices, heavy machinery is used to prepare the seedbed for planting, to control weeds, and to harvest the crop. The use of heavy equipment has many advantages in saving time and labor, but can cause compaction of soil and disruption of the natural soil organisms. The problem with soil compaction is that increased soil density limits root penetration depth and may inhibit proper plant growth.

Alternative practices generally encourage **minimal tillage** or **no tillage methods**. With proper planning, this can simultaneously limit compaction, protect soil organisms, reduce costs (if performed correctly), promote water infiltration, and help to prevent topsoil erosion (Figure $Page11.5.3$).



Figure $Page11.5.3$. Farmers should consider no-till farming as the most important tool to prevent loss of soil moisture.

Tillage of fields does help to break up clods that were previously compacted, so best practices may vary at sites with different soil textures and composition. Another aspect of soil tillage is that it may lead to more rapid decomposition of organic matter due to greater soil aeration. Over large areas of farmland, this has the unintended consequence of releasing more carbon and nitrous oxides (greenhouse gases) into the atmosphere, thereby contributing to global warming effects. In no-till farming, carbon can actually become sequestered into the soil. Thus, no-till farming may be advantageous to sustainability issues on the local scale and the global scale. No-till systems of conservation farming have proved a major success in Latin America and are being used in South Asia and Africa.

Crop Rotation

Crop rotations are planned sequences of crops over time on the same field. Rotating crops provides productivity benefits by improving soil nutrient levels and breaking crop pest cycles. Farmers may also choose to rotate crops in order to reduce their production risk through diversification or to manage scarce resources, such as labor, during planting and harvesting timing. This strategy reduces the pesticide costs by naturally breaking the cycle of weeds, insects and diseases. Also, grass and legumes in a rotation protect water quality by preventing excess nutrients or chemicals from entering water supplies.

AN ALTERNATIVE TO SPRAYING: BOLLWORM CONTROL IN SHANDONG

Farmers in Shandong (China) have been using innovative methods to control bollworm infestation in cotton when this insect became resistant to most pesticides. Among the control measures implemented were:

1. The use of pest resistant cultivars and interplanting of cotton with wheat or maize.
2. Use of lamps and poplar twigs to trap and kill adults to lessen the number of adults.
3. If pesticides were used, they were applied on parts of cotton plant's stem rather than by spraying the whole field (to protect natural enemies of the bollworm).

These and some additional biological control tools have proved to be effective in controlling insect populations and insect resistance, protecting surroundings and lowering costs.

The Future of the Sustainable Agriculture Concept

Many in the agricultural community have adopted the sense of urgency and direction pointed to by the sustainable agriculture concept. Sustainability has become an integral component of many government, commercial, and non-profit agriculture research efforts, and it is beginning to be woven into agricultural policy. Increasing numbers of farmers and ranchers have embarked on their own paths to sustainability, incorporating integrated and innovative approaches into their own enterprises.

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Page 11.S: Conventional and Sustainable Agriculture (Summary)

Summary

In agriculture and horticulture, soil generally refers to the medium for plant growth, typically material within the upper meter or two. Soil plays a key role in plant growth. Beneficial aspects to plants include providing physical support, heat, water, nutrients, and oxygen. Heat, light, and oxygen are also obtained by the atmosphere, but the roots of many plants also require oxygen. The prevailing agricultural system has delivered tremendous gains in productivity and efficiency. Food production worldwide has risen in the past 50 years. On the other hand, agriculture profoundly affects many ecological systems. Negative effects of current practices include ecological concerns, economic and social concerns and human health concerns. Pesticides from every chemical class have been detected in groundwater and are commonly found in groundwater beneath agricultural areas. Despite impressive production gains, excessive use of pesticides has proven to be ecologically unsound, leading to the destruction of natural enemies, the increase of pest resistance pest resurgence and outbreaks of secondary pests. These consequences have often resulted in higher production costs and lost markets due to undesirable pesticide residue levels, as well as environmental and human health costs. Alternative and sustainable practices in farming and land use include organic agriculture, integrated pest management and biological control.

Review Questions

1. Which of the following is not one of the five soil-forming factors?
   A. Climate
   B. Organisms
   C. Relief
   D. Transpiration rate
   E. Time
2. You analyze a soil sample for a farmer that has been dealing with fertility issues on her land. You find that it is deficient in all of the soil-derived macronutrients. Which one of the following is macronutrient derived from the soil?
   1. carbon
   2. nitrogen
   3. hydrogen
   4. iron
   5. oxygen
3. The farmer adjacent to your land plants a single crop (soybean) over their entire 100 hectare field. This practice is known as a…
   A. Monoculture
   B. Crop plot
   C. Agriplot
   D. Rotational farming
   E. Millibar
4. Salinization is bad for farmers because it results in…
   A. Pesticide resistance
   B. Increased salts in the soil
   C. Nutrient-poor soils
   D. Blight
   E. Desertification
5. Besides being long-lasting, persistent organic pollutants share which of the following characteristics:
   A. accumulate in higher trophic levels and are toxic
   B. accumulate in lower trophic levels and are toxic
   C. accumulate in higher trophic levels and are infectious biological agents
   D. accumulate in lower trophic levels and are infectious biological agents
   E. Are toxic and infectious

6. The grasshopper effect explains which one of the following phenomena?
   A. The mass migration patterns of insects that are similar to, and include, grasshoppers
   B. The lowering of nutrient capacity in soils due to the action of certain types of organisms
   C. The long-range movement of certain types of pollutants across different regions of the Earth
   D. The long-range atmospheric distribution of soil following tilling by farm equipment
   E. The spread of invasive species through international trade in potted plants
7. An important goal of integrated pest management is to reduce the amount of pests while also…
   A. Reducing the amount of genetically modified crops grown
   B. Reducing the amount of fertilizer used
   C. Introducing species that prey upon and destroy pest species
   D. Integrating market-based strategies for maximization of profits
   E. Reducing the amount of synthetic chemical pesticides used
8. Which one of the following describes the use of organisms to control pests?
   A. Bioremediation
   B. Intercropping
   C. Species niche partitioning
   D. Vector control
   E. Biological control
9. What practice allows farmers to improve soil fertility, diversify their crops, and reduce pesticide costs by naturally breaking the cycle of weeds, insects, and diseases?
   A. Monoculture
   B. Biological control
   C. Crop sharing
   D. Crop rotation
   E. Soil tilling
10. Which one of the following is more indicative of conventional agriculture, and not sustainable agriculture?
   A. Biological control
   B. Intercropping
   C. Monocultures
   D. Integrated pest management
   E. Minimal tillage

See Appendix for answers

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12: Environmental Effects of Forestry

Learning Objectives

After completing this chapter, you will be able to:

1. Explain how forest harvesting removes nutrient capital from the site.
2. Outline how forestry can damage aquatic ecosystems, and how many of those effects can be avoided.
3. Describe how clear-cutting affects biodiversity.
4. Explain the special qualities of old-growth forest, and how they are affected by timber harvesting.
5. Discuss ecological consequences of the conversion of natural forest into plantations.
6. Explain the concept of integrated forest management.

Introduction

Forestry includes both the harvesting of trees and the management of post-harvest succession to foster the regeneration of another forest. Forest science guides these activities by providing an understanding of the environmental factors that affect the productivity of trees. The primary goal of commercial forestry is to provide sustainable harvests of tree biomass that can be used to manufacture lumber, paper, and other industrial products, or as a source of bio-energy. Secondary goals are related to the management of hunted animals (such as deer and fish) on forest landscapes, and sometimes the designation of certain areas as protected (where no timber harvesting occurs).

Forestry is an important economic sector in many countries. This is the case in Canada, where a large industrial enterprise depends on a continuous supply of tree biomass for the production of products that have a great economic value ($34 billion in 2013; see Chapter 14 for forestry-related economics).

Of course, to achieve these economic benefits, trees must be harvested from extensive areas of mature forest. In Canada, clear-cutting is the most commonly used method of forest harvesting – this method removes all of the economically useful trees on a site at the same time. Clear-cutting accounts for about 90% of the annual timber harvest.

However, clear-cutting is not the same as deforestation. Deforestation involves the permanent conversion of a forest into some other kind of ecosystem, such as an agricultural or urbanized land-use. In Canada and most other developed countries, industrial clear-cutting is generally followed by the regeneration of another forest. In fact, it is common practice to manage the post-harvest succession to speed up the rate of regeneration of trees. This allows the next harvest to be made after a relatively short time, so more profit can be made. (This period of time is known as a harvest rotation.) In this sense, forestry as it is usually practised does not result in a net deforestation, and if appropriately managed the forest resource is not depleted. Even though hundreds of thousands of hectares are harvested each year in Canada (638-thousand ha in 2013), the net deforestation is essentially zero (Table 14.11).

Timber harvesting can be viewed as a disturbance of the forest ecosystem, followed by regeneration. Additional disturbances are associated with silvicultural activities, such as preparing the site for planting, thinning dense stands, and applying herbicide or insecticide to deal with pest problems. Silviculture, the branch of forestry that involves tending and growing forests, is practised over an extensive area in Canada. For instance, about 67% of the area harvested (in 2012) is planted to tree seedlings (the other 33% regenerates naturally.) Some planted areas are managed intensively to develop a plantation, which is an anthropogenic forest, but one that lacks many of the ecological and aesthetic values of natural forest.

In this chapter we examine some of the ecological effects of timber harvesting and silviculture, with a focus on site quality, hunted animals, and biodiversity. Additional effects of forestry are examined in other chapters: pesticide spraying in Chapter 22, implications for carbon storage in Chapter 17, and tropical deforestation and global biodiversity in Chapter 26.

Forest Harvesting and Site Capability

In Chapter 14, we defined site capability (or site quality) as the potential of land to sustain the productivity of agricultural crops. This is also relevant to forestry, in terms of the ability of land to sustain the productivity of trees. Site capability is a complex attribute that involves the amounts of nutrients and organic matter in soil, the availability of moisture, and other factors affecting

plant growth. These factors are influenced by soil type, climate, drainage, rate of nutrient cycling, and the kinds of plant and microbial communities that are present.

The ability of soil to supply plants with nutrients is a critical aspect of site capability. In large part, this ecological function depends on the nutrient capital of a site, which is the amount of nutrients present in the soil, living vegetation, and dead organic matter. When trees are harvested, the nutrients in their biomass are also removed, which can deplete the nutrient capital of the site.

A stand of forest may be harvested using a variety of methods, which vary in the amount of biomass and nutrients that are removed from the site. A selection harvest is a relatively "soft" method because it involves the harvesting of only some of the trees from a stand, leaving others behind and the structure of the forest substantially intact. The most intensive harvest is a clear-cut, in which all economically useful trees are removed. The smallest clear-cuts, typically involving a hectare or less, are known as a group-selection harvest. More typically, clear-cuts entail the harvesting of trees from larger areas, on the order of 20-100 ha. The largest clear-cuts may extend over hundreds, and even thousands, of hectares. However, such extensive operations are unusual, and are usually associated with the salvaging of trees that have been damaged by a wildfire, windstorm, or insect infestation.

There are also some less intensive methods of clear-cutting. A shelterwood harvest is a staged clear-cut, in which some larger trees of economically desirable species are left standing during the initial cut. These provide a seed source and a partially shaded environment that encourages natural regeneration. Once the regeneration is well underway, the large "leave" trees are harvested. A strip-cut is another kind of staged harvest, in which long and narrow clear-cuts are made at intervals, with uncut forest left in between to provide a source of seed to regenerate trees in the cut strips. Once the regeneration is established, another strip-cut is made, again leaving intact forest on one of the sides. This system of progressive strip-cutting continues until all the forest in the management block (the specific area being managed this way) has been harvested. Typically, an area is harvested in three to four strips. To regenerate trees on the final strips, foresters may rely on advanced regeneration – that is, on small individuals of tree species that existed in the stand prior to harvesting and that survived the disturbance of clear-cutting. Alternatively, they may plant the last strip with seedlings.



Image 23.1. This photo shows a three-year-old shelterwood cut of hardwood forest in Nova Scotia. About 60% of the trees were removed during the harvest, but many of the "best" trees were left to grow into high-quality sawlogs and to shed seeds to promote regeneration. This treatment produces a complex habitat that supports a mixture of birds and other wildlife typical of both clear-cuts and mature forest. Source: B. Freedman.

Clear-cutting systems also vary in how intensively the biomass of individual trees is harvested. The usual stem-only harvest involves the removal of tree trunks, leaving the roots, stumps, and logging "slash" (cut branches and foliage) on the site. The harvested logs can then be processed into lumber or pulp for manufacturing paper. A whole-tree harvest is more intensive because it removes all of the above-ground biomass of the trees, including the branches and foliage. This intensive kind of harvest will recover considerably more biomass than a stem-only cut, which is an advantage if the wood is to be used as a source of bio-energy.

Nutrient Losses during Harvesting

Although intensive harvests such as a whole-tree clear-cut increases the yield of biomass, there is also considerably more removal of nutrients. Some forest scientists have suggested that the nutrient removals from whole-tree harvests could degrade the capability of sites to sustain tree productivity. The problem would be especially severe if the harvests are conducted over a short rotation. This might not allow enough time for the nutrient capital to recover by natural inputs, such as by precipitation, nitrogen fixation, and weathering of minerals (Figure 23.1).

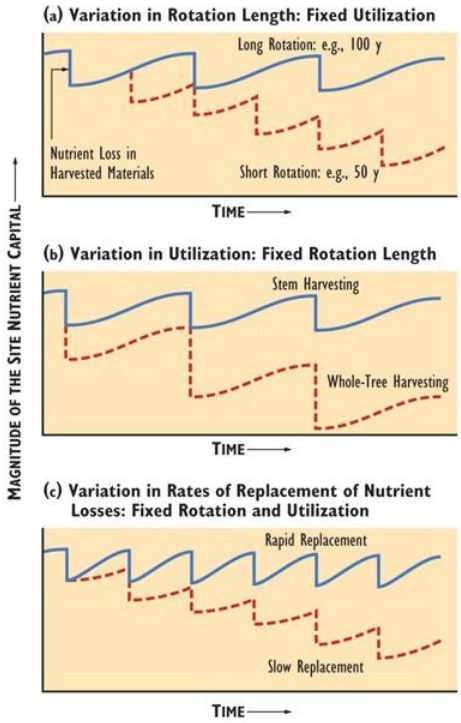


Figure 23.1. Effects of Harvest Intensity and Length of Rotation on Nutrient Capital. Diagram (a) suggests that a relatively long rotation can allow harvested nutrients to be replenished by natural inputs through rainfall, weathering of minerals, nitrogen fixation, and other means. An adequate post-harvest recovery means that harvesting is sustainable with respect to the nutrient capital of the site. Under the shorter rotation (dashed line), the harvested nutrients are not totally replenished between successive clear-cuts, resulting in a degradation of nutrient capital. Site capability can also be degraded by an increase in the intensity of the harvest. This is illustrated in diagram (b), in which a whole-tree clear-cut removes twice as much nutrient as a stem-only harvest. Diagram (c) indicates that fertile sites (solid line) are less likely to be degraded by intensive harvests over short rotations, compared with less fertile sites (dashed line). Source: Modified from Kimmins (2003).

Site impoverishment caused by intensive cropping is a well-known problem in farming, in which severely degraded land may have to be abandoned for some or all agricultural purposes. However, usually this problem can be managed, to a degree, by applying fertilizer or composted organic matter to the land. Sometimes, however, the degradation of site capability, especially of tilth, is too severe, and this simple mitigation is not successful. Of course, the harvest rotation in agriculture is usually annual, whereas in forestry it ranges from about 20 to 100 years. However, each timber harvest involves the removal of a huge quantity of biomass, and thus of nutrients.

Compare, for example, the amounts of biomass and nutrients removed by clear-cuts of a conifer forest in Nova Scotia (Table 23.1). In this case, a whole-tree clear-cut yielded 30% more biomass than a stem-only harvest. The increased yield may be an advantage, particularly if the harvest is to be used for energy production. The increased harvest of biomass is, however, due to the removal of nutrient-rich tissues such as foliage and small branches. Consequently, the whole-tree harvest removed up to twice as many nutrients as did the stem-only clear-cut. In effect, a 30% increase in biomass yield by the whole-tree method was “purchased” at the ecological “expense” of 54-99% increases in the removal of nutrients.

Component	Biomass (t/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
(a) Stem-only clear-cut						
Tree stems	105.2	98	16	92	181	17
(b) Whole-tree clear-cut						
Tree stems	117.7	120	18	76	219	20
Branches & foliage	34.8	119	17	57	118	17
Total harvest	152.5	239	35	133	337	37
Percentage increase	30%	99%	93%	74%	54%	81%
Nutrients in forest floor		900	62	110	290	32
Nutrients in mineral soil (top 30 cm)		3,860	1,220	13,300	5,460	1,740

Table 23.1. Removal of Biomass and Nutrients by Clear-Cuts of a Conifer Forest in Nova Scotia. This study involved weighing the biomass harvested by (a) a stem-only clear-cut and (b) a whole-tree clear-cut (each 0.5 ha). Nutrient concentrations were determined in subsamples of the biomass and were used to calculate the amounts of nutrients removed. "Percentage increase" refers to the whole-tree removals, compared with stem-only removals. Source: Data from Freedman et al. (1981).

Unfortunately, there are few studies that allow foresters to compare the productivity of subsequent harvest rotations on the same site. Such studies would take more than 50-100 years, requiring several generations of foresters! Therefore, it is difficult to evaluate the implications of nutrient removal by clear-cutting. Overall, however, it appears that a degradation of site nutrient capital is a less severe problem in forest harvesting than in agriculture. Consequently, nutrient removals by timber harvesting should be viewed as a potential long-term problem. Because forestry is an economically important activity, and the maintenance of site capability is critical to the sustainability of the enterprise, scientists should continue to study the effects of harvesting on nutrient capital. In the short term, however, forestry causes more immediate kinds of damage to site capability and biodiversity that deserve our attention.

Leaching of Nutrients

The disturbance of forested land can increase the rate at which dissolved nutrients are transported downward into the soil with percolating rainwater (a process known as leaching). If the nutrients leach deeper into the soil than tree roots can penetrate, they are effectively lost from the "working" nutrient capital of the site. Eventually, leached nutrients can find their way into groundwater and surface waters.

The nutrients with the greatest tendency to leach are nitrate and potassium, both of which are highly soluble in water. However, calcium, magnesium, and sulphate may also leach in significant amounts. Of course, following a clear-cut, any nutrient losses by leaching are in addition to that removed with tree biomass.

A well-known study of nutrient leaching caused by forest disturbance was done at Hubbard Brook, New Hampshire. This large-scale experiment involved felling all of the trees on a 16-ha watershed, but without removing any biomass – the cut trees were left on the ground. The watershed was then treated with herbicide for three years to suppress regeneration. This experiment was designed to examine the effects of intense disturbance, by de-vegetation, on biological control of watershed functions such as nutrient cycling and hydrology. The research was not intended to examine the effects of a typical forestry practice.

Overall, during a 10-year period following the cutting, the de-vegetated watershed lost 50 kg/ha-year of NO_3-N (i.e., nitrogen in the form of nitrate), 45 kg/ha-y of Ca, and 17 kg/ha-y of K in streamflow (Bormann and Likens, 1994; Figure 23.2 shows data for the first three years, which were the most dramatic). The losses were much larger than from an undisturbed reference watershed: 4.3 kg/ha-y of NO_3-N, 13 kg/ha-y of Ca, and 2.2 kg/ha-y of K.

In part, the increased losses of nutrients were due to a 31% increase in the yield of water from the de-vegetated watershed (during the first three years after cutting). The increased streamflow was caused by the disruption of transpiration from plant foliage. However, increases in nutrient concentration in the streamwater were more important: during the first three years, NO_3 increased by an average factor of 40; K, by 11; Ca, by 5.2; and Mg, by 3.9. The losses of N, Ca, and Mg in the streamwater were similar to their amounts in the above-ground biomass of the forest.

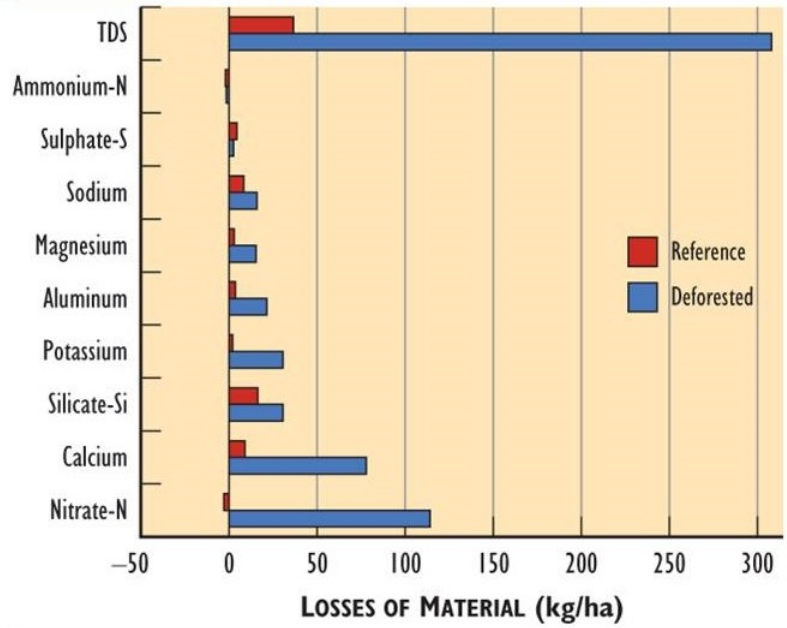


Figure 23.2. Nutrient Losses in Streamflow after Deforestation. The experimental watersheds are located at Hubbard Brook, New Hampshire. The data represent "net flux", or the difference between inputs from precipitation and outputs due to leaching and streamflow. The data are for the first three years following deforestation of a 16-ha watershed, compared with an uncut reference watershed of similar size. Losses are stated in kilograms per hectare per three-year period. TDS = total dissolved solids. Source: Modified from Bormann and Likens (1979).

Because this experiment in de-vegetation did not involve a typical forestry practice, the measured effects are unrealistically large. However, watershed-level studies of clear-cutting have also found an increase in nutrient leaching, although to a lesser degree than that caused by the de-vegetation at Hubbard Brook. For example, in the first three years after clear-cutting a 391 ha watershed in New Brunswick, there was an increased loss of nitrate in streamwater of 7 kg NO_3-N/ha-yr (Krause, 1982). A study of nine clear-cut watersheds in New Hampshire found an average nitrate loss of 18 kg NO_3-N/ha-y during the first four years, compared with 3.5 kg/ha-y for five uncut watersheds (Martin et al., 1986). In addition, calcium losses from the clear-cuts averaged 28 kg/ha-y, compared with 13 kg/ha-y for reference watersheds, while potassium losses were 6 kg/ha-y compared with 2 kg/ha-y. However, other studies have found smaller effects of clear-cutting on nutrient losses with streamflow, especially if only a portion of the watershed was cut.

Nitrate and other highly soluble ions are leached from watersheds after clear-cutting (and after other disturbances, such as wildfire) for several reasons. First, disturbance stimulates the activity of microbes involved in the decomposition of organic matter. This occurs because removal of the tree canopy results in warming of the forest floor and surface soil, and decreased uptake by plants leads to an increase of soil nutrients and moisture. Second, disturbance often stimulates the microbial processes of ammonification and nitrification (see Chapter 5), resulting in increased rates of production of nitrate, which is extremely soluble and readily lost from soil.

Forestry and Erosion

Forestry activities can cause severe losses of soil, or erosion, particularly in terrain with steep slopes. In most cases, erosion is triggered by improperly constructing logging roads, using streams as trails to haul logs, running log-removal trails down slopes instead of along them, and harvesting trees from steep slopes that are extremely vulnerable to soil loss. In general, however, road building is the most important cause of erosion on forestry lands, especially where culverts (channelled stream crossings) are not sufficiently large or numerous, or are poorly installed.

Severe erosion causes many environmental damages. In extreme cases, the loss of soil may expose bedrock, making forest regeneration impossible. Soil loss also represents a depletion of site nutrient capital. Erosion also causes secondary damage to aquatic habitats, including the deposition of silt (or siltation), which covers gravel substrates that are important to spawning fish. Also, the shallower water increases the risk of flooding.

However, in many cases erosion is a largely avoidable environmental effect of forestry. The irresponsible practices that can cause erosion are restricted by provincial regulations and occur much less frequently now than in the past. Practices that help to reduce erosion include the following:

- planning the route of forest roads to avoid stream crossings as much as possible
- installing a sufficient number of properly sized culverts
- avoiding the disturbance of stream channels by heavy equipment
- leaving buffer strips of uncut forest beside watercourses
- using log-removal practices that avoid disturbance of the forest floor (such as cable yarding, in which a tall spar anchors cables radiating into the clear-cut, which allows logs to be dragged to a central place without the use of a wheeled skidder)
- allowing vegetation to regenerate quickly, which speeds the re-establishment of biological moderation of erosion
- deciding to selectively harvest, or to not harvest, steep sites that are highly vulnerable to erosion

It has become a common practice to leave strips of uncut forest beside streams, rivers, and lakes. These buffer zones greatly reduce the erosion of streambanks, eliminate temperature increases in the water, maintain riparian (lake- and stream-side) habitat for wildlife, and mitigate some of the aesthetic damage from forest harvesting.

While it is widely accepted that riparian buffers provide important benefits, there is no consensus about how wide the uncut strips should be. This is an economically important consideration, because large areas of valuable timber are withdrawn from the potential harvest when buffer strips are left. The requirements in New Brunswick, for example, are for a 30-m buffer on each side of a watercourse, with wider buffers recommended in some circumstances (such as 60 m if the slope exceeds 24°, and up to 100 m beside waters that are used for recreation or as a source of drinking water).

In some cases, selective harvesting of trees may be allowed within riparian buffers, as long as this does not compromise the ecological services provided by these special management zones.

Forestry and Hydrology

The cover of forest on a watershed has a strong influence on its hydrology. Large amounts of water are evaporated into the atmosphere by vegetation, especially by trees because they have so much foliage (this is transpiration; evapotranspiration includes evaporation from non-living surfaces). In the absence of transpiration, an equivalent quantity of water would leave the watershed as streamflow or as seepage to deeper groundwater.

For example, studies of four well-forested watersheds in Nova Scotia found that evapotranspiration was equivalent to 15-29% of the annual input of water by precipitation (rain plus snow), with runoff in streams accounting for the other 71-85% (these watersheds have no substantial drainage to deep groundwater; Freedman et al., 1985).

The hydrologic budget of watersheds is extremely seasonal, particularly in the temperate and boreal climates that are typical of forested regions of Canada. This can be illustrated by the watershed of the Mersey River in Nova Scotia (Figure 23.3). The annual input of water from precipitation was 146 cm/y, with 82% arriving as rain and 18% as snow. About 62% of the annual input was dispersed by riverflow and 38% by evapotranspiration. Evapotranspiration is highest during the growing season, which results in relatively sparse riverflow. Runoff is greater during late autumn and early winter, when there is little transpiration because deciduous trees have dropped their foliage, and even conifers are in a quiescent state. However, much of the precipitation during that period recharges groundwater storage, which had been depleted by the uptake of water by vegetation during the summer. Runoff is greatest during the spring, when the accumulated snowpack melts, and that results in a spate of riverflow.

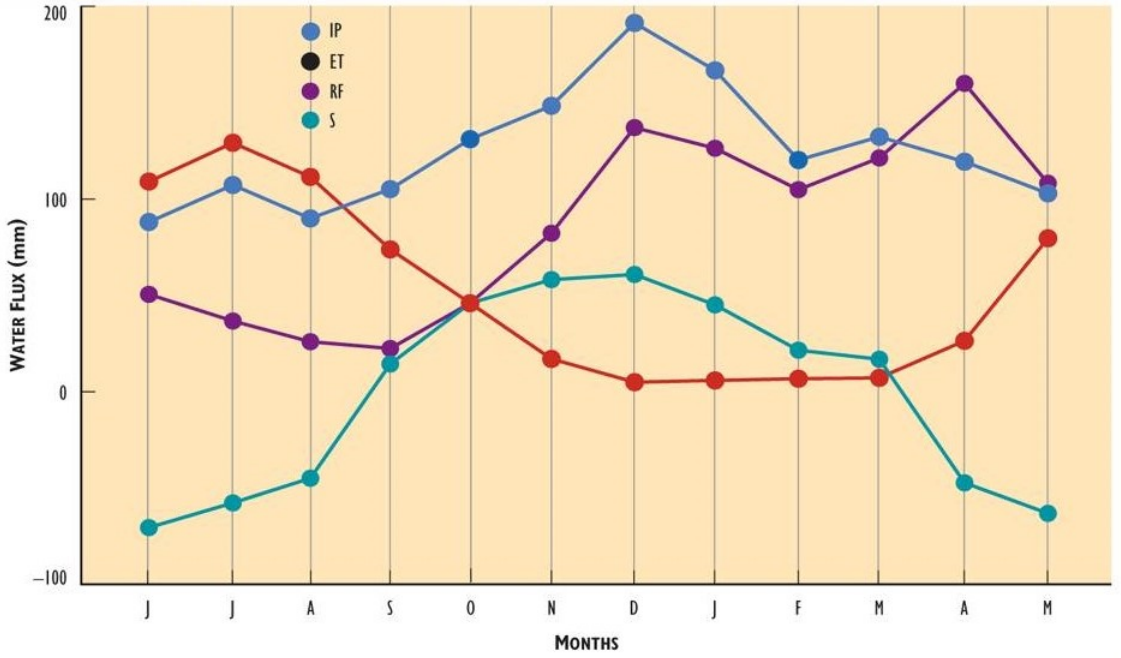


Figure 23.3. Seasonal Hydrology of the Mersey River in Nova Scotia. Water inputs from incident precipitation (IP) into the 723 km^2 watershed, and riverflow (RF) from the watershed, are displayed as monthly averages for the period 1968-1982. Evapotranspiration (ET) was estimated using a climatic model, and groundwater storage (S) was calculated as IP – RF – ET. Source: Modified from Freedman et al. (1985)

Disturbances such as wildfire and timber harvesting alter the hydrology of watersheds. The seasonality and amounts of flow can change, and erosion and flooding may occur downstream. Some poorly drained sites may become wetter, because reduced transpiration can raise the water table. In general, the increase in streamflow is related to the proportion of the watershed that was disturbed. If an entire watershed is clear-cut, the increase in streamflow can be as much as 40% in the first year. The increase is proportionately less after partial cuts.

Clear-cuts usually regenerate quickly, and in some cases the vigorous regrowth of shrubs and herbs can restore most of the original foliage area in as few as four to six years. Consequently, the biggest increases in streamflow occur in the first year after cutting, followed by rapid recovery to the pre-harvest condition. In the temperate and boreal climates prevalent in much of Canada, the largest increases in streamflow occur during the late spring, summer, and early autumn, these being the seasons when transpiration is most important.

Hydrology can also be affected by a change in the type of forest that is dominant on a watershed. For example, if an area of hardwood forest is converted into conifer plantations, the annual streamflow may decrease. This happens because the conifers maintain their foliage throughout the year, and so extend the transpiration season into times when angiosperm trees lack foliage.

Weeds and Reorganization

Clear-cuts usually regenerate rather quickly. Initially, however, most of the regenerating biomass involves plants other than the tree species that foresters consider desirable. As a result, the vigorous regrowth is often regarded as being detrimental to silvicultural objectives. Such non-crop plants may be viewed as “weeds,” and their abundance may be controlled by a herbicide application (see Chapter 22).

However, a rapid re-vegetation of clear-cuts and other disturbed lands does provide important ecological benefits. The regenerating plants influence the ecological “reorganization” of disturbed lands. They re-establish a measure of biological control over nutrient cycling, erosion, and hydrology, while also restoring habitat for animals.

For example, during the first few years after clear-cutting, fast-growing vegetation restores a high rate of nutrient uptake from the soil. Through this uptake, the regenerating vegetation acts as a “sponge” that absorbs some of the soluble nutrients that might otherwise leach from the site. Eventually, the early successional plants die, and their nutrients are recycled by decomposition and made available to trees. In addition, the re-vegetation restores habitat for birds, mammals, and other wildlife. Clearly, the early

reorganization phase of succession is enhanced by the rapid regeneration of many plant species, including those considered to be weeds by foresters.

Forestry and Biodiversity

Clear-cutting and other forestry practices inflict intense disturbances on forests. They cause dramatic changes in the habitat available to support plants, animals, and microbes, as well as their various communities. Some species benefit from habitat changes that occur because of forestry, but others suffer damage.

In the following sections, we examine the effects of forestry on aspects of Canadian biodiversity – the richness of biological variation in our country. The effects of clear-cutting on plants, mammals, birds, and fish will be examined because these groups are relatively well studied and are considered to be important by our society.

Vegetation

Any severe disturbance results in changes in the dominant species of plants that are living on a site. Because they have such a great influence on local environmental conditions, trees are the dominant organisms in forests. After clear-cutting, many smaller plants take advantage of the relatively uncompetitive conditions that occur, and they dominate the initial stages of the post-harvest succession. They are then reduced in abundance, or even eliminated from the community, once several decades of regeneration have gone by and tree-sized plants re-establish their dominance.

Many plants of early post-cutting succession can only be successful in open habitats –they are intolerant of the shade and other stressful conditions beneath a forest canopy. These relatively short-lived ruderal plants can typically disperse widely, a propagation strategy made necessary because of their ephemeral habitat (see Chapter 9). Ruderal plants that can proliferate in recently disturbed forests include asters, goldenrods, grasses, and sedges. A specific example is the fireweed (Chamerion angustifolium), a purple-flowered herb that is often abundant after wildfire (hence its name) and also after clear-cutting. Some woody plants are also ruderals, because they are most abundant during the recovery after disturbance. Examples are the red raspberry (Rubus strigosus), pin cherry (Prunus pensylvanica), and elderberry (Sambucus racemosa). Because of their need for open, recently disrupted habitat, ruderal plants benefit from clear-cutting and other disturbances that are associated with forestry.

Unlike ruderal plants, some other species are tolerant of the environmental stress that occurs beneath a closed forest canopy. Examples are the white trillium (Trillium grandiflorum), shield fern (Dryopteris marginalis), feather mosses (such as Pleurozium schreberi and Hylocomium splendens), and certain lichens, such as lungwort (Lobaria pulmonaria). These species are not tolerant of open conditions, and they decline after clear-cutting. Once suitable conditions re-develop, these plants may again increase in abundance.

In general, once a clear-cut has had two to four years to regenerate, the plant community is actually richer in species than the mature forest that was harvested (this is particularly true of vascular plants). The increase in species diversity occurs because recently disturbed habitats are relatively flush in such resources as light, nutrients, and water. This allows many species of low-growing plants to be supported, including a diversity of ruderal ones. In comparison, stressful habitats, such as the understorey beneath a mature forest canopy, support fewer species of plants.

A study of a hardwood forest in Nova Scotia illustrates the species-rich nature of vegetation after a clear-cut (Crowell and Freedman, 1994). That study examined stands of mature forest, plus clear-cuts of various age. The number of plant species in the ground vegetation (shorter than 2 m) averaged 11/m^2 on two one-year-old clear-cuts, and increased to 14/m^2 on six-year-old clear-cuts. Mature forest and clear-cuts older than 30 years had fewer species – only 3-6/m^2 in stands with a closed canopy dominated by maple trees, but 9-11/m^2 in birch-dominated stands, which have a more open canopy. This comparison suggests that many plants, especially ruderals, can utilize open habitats associated with clear-cutting. However, species that need mature forest as habitat are threatened by this kind of disturbance.

Conclusions

Forestry is a key economic sector in Canada, each year affecting millions of hectares of landscape. Timber harvesting and management of the subsequent regeneration cause many environmental changes, including decreases of carbon storage, alterations of hydrology, erosion, and effects on the habitat of wildlife. Because timber harvesting and silvicultural practices are severe disturbances of forested sites, some environmental damage is inevitable. To a large degree, however, many of the damages could be

mitigated by adopting different forestry practices than are currently used. These include less use of the predominant clear-cutting system, and replacing it with softer practices such as selection harvesting. Greater attention to the protection of aquatic habitat is also necessary, such as retaining buffer strips of uncut forest along all watercourses. Some damage to the habitat of wildlife on cutovers can also be mitigated, for instance, by retaining cavity trees and by greater reliance on natural regeneration rather than on plantations. It is also necessary to protect large areas of natural forest from intensive resource harvesting. This requires the implementation of a connected network of protected areas that is sufficient to conserve those species and ecological communities that are incompatible with use of the landscape for forestry purposes.

Questions for Review

1. How do forestry practices threaten the nutrient capital and site quality of harvested stands?
2. How does timber harvesting affect the hydrology of streams and rivers?
3. What elements should an integrated management plan include for a typical forested watershed in your region? Consider the needs to ensure a constant supply of timber, deer, sportfish, clean water, and habitat for non-game species.
4. What are the characteristics of a typical old-growth forest in the region where you live? Do you think that the special values of the old-growth forest can be accommodated by forestry, or can old-growth forest be preserved only by creating large protected areas where trees are not harvested? What are the economic implications of setting aside such large tracts of potentially valuable timber? What are the ecological implications?

Questions for Discussion

1. Consider a typical forest in the region where you live. What are the dominant species of trees, other plants, and animals that live in that forest? What are some important interactions among those species? Consider, for example, the habitat needs of certain animals, including their foods.
2. Are forest products important in your life and in the functioning of your community? Compile a list that shows how trees are used for bio-energy, lumber, paper, and other products. Also consider non-timber uses of forests, such as hunted animals, recreation, carbon storage, and the provision of clean air and water.
3. How might forest resources make a larger contribution to the Canadian economy, or to that of your region? Would it be possible, for example, to harvest more wood without degrading the timber resource? Could more people be employed in woodland operations if harvesting and management activities were less mechanized? Consider also the prospects for reducing the export of raw materials, such as logs, through increased local processing into manufactured products.
4. Why is it essential that a large and connected system of protected areas be a key part of any landscape-scale plan for ecologically sustainable forestry?

Exploring Issues

1. A proposal is being made to build a lumber mill in an area that is now wilderness. About 40% of the forest in the area is in an old-growth condition. You are an ecologist, working as part of a team of scientists to assess the potential environmental impacts of the forest management plan to supply timber to the proposed sawmill. Your responsibility is to consider the sustainability of the supply of timber and other forest resources, as well as effects on rare species and natural ecosystems. What would you examine to ensure that the forest management is ecologically sustainable?

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CHAPTER OVERVIEW

13: Air Pollution, Climate Change, and Ozone Depletion

Learning Outcomes

- Identify sources of air pollution
- List common air pollutants
- Explain how the greenhouse effect causes the atmosphere to retain heat
- Explain how we know that humans are responsible for recent climate change
- List some effects of climate change
- Identify some climate change policies and adaptation measures

Page 13.1: Atmospheric Pollution

Page 13.2: Ozone Depletion

Page 13.3: Acid Rain

Page 13.4: Climate Change

Page 13.5: Chapter Resources

Thumbnail image - Traffic congestion is a daily reality of India's urban centers. Slow speeds and idling vehicles produce, per trip, 4 to 8 times more pollutants and consume more carbon footprint fuels, than free flowing traffic. This 2008 image shows traffic congestion in Delhi.

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Page 13.1: Atmospheric Pollution

Air pollution occurs in many forms but can generally be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Chemicals discharged into the air that have a direct impact on the environment are called **primary pollutants**. These primary pollutants sometimes react with other chemicals in the air to produce **secondary pollutants**.

Air pollution is typically separated into two categories: outdoor air pollution and indoor air pollution. **Outdoor air pollution** involves exposures that take place outside of the built environment. Examples include fine particles produced by the burning of coal, noxious gases such as sulfur dioxide, nitrogen oxides and carbon monoxide; ground-level ozone and tobacco smoke. **Indoor air pollution** involves exposures to particulates, carbon oxides, and other pollutants carried by indoor air or dust. Examples include household products and chemicals, out-gassing of building materials, allergens (cockroach and mouse dropping, mold, pollen), and tobacco smoke.

Sources of Air Pollution

A **stationary source** of air pollution refers to an emission source that does not move, also known as a point source. Stationary sources include factories, power plants, and dry cleaners. The term **area source** is used to describe many small sources of air pollution located together whose individual emissions may be below thresholds of concern, but whose collective emissions can be significant. Residential wood burners are a good example of a small source, but when combined with many other small sources, they can contribute to local and regional air pollution levels. Area sources can also be thought of as non-point sources, such as construction of housing developments, dry lake beds, and landfills.

A **mobile source** of air pollution refers to a source that is capable of moving under its own power. In general, mobile sources imply "on-road" transportation, which includes vehicles such as cars, sport utility vehicles, and buses. In addition, there is also a "non-road" or "off-road" category that includes gas-powered lawn tools and mowers, farm and construction equipment, recreational vehicles, boats, planes, and trains.

Agricultural sources arise from operations that raise animals and grow crops, which can generate emissions of gases and particulate matter. For example, animals confined to a barn or restricted area produce large amounts of manure. Manure emits various gases, particularly ammonia into the air. This ammonia can be emitted from the animal houses, manure storage areas, or from the land after the manure is applied. In crop production, the misapplication of fertilizers, herbicides, and pesticides can potentially result in aerial drift of these materials and harm may be caused.

Unlike the above mentioned sources of air pollution, air pollution caused by **natural sources**is not caused by people or their activities. An erupting volcano emits particulate matter and gases, forest and prairie fires can emit large quantities of "pollutants", dust storms can create large amounts of particulate matter, and plants and trees naturally emit volatile organic compounds which can form aerosols that can cause a natural blue haze. Wild animals in their natural habitat are also considered natural sources of "pollution".

Six Common Air Pollutants

The most commonly found air pollutants are *particulate matter*, *ground-level ozone*, *carbon monoxide*, *sulfur oxides*, *nitrogen oxides*, and *lead*. These pollutants can harm health and the environment, and cause property damage. Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. The U.S. Environmental Protection Agency (EPA) regulates them by developing criteria based on considerations of human and environmental health.

1. **Ground-level ozone** is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground level ozone can also have harmful effects on sensitive vegetation and ecosystems. (Ground-level ozone should not be confused with the ozone layer, which is high in the atmosphere and protects Earth from ultraviolet light; ground-level ozone provides no such protection).
2. **Particulate matter**, also known as particle pollution, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals,

metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects.

3. **Carbon monoxide** (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death.
4. **Nitrogen dioxide** (NO_2) is one of a group of highly reactive gasses known as "oxides of nitrogen," or nitrogen oxides (NOx). Other nitrogen oxides include nitrous acid and nitric acid. EPA's National Ambient Air Quality Standard uses NO_2 as the indicator for the larger group of nitrogen oxides. NO2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO2 is linked with a number of adverse effects on the respiratory system.
5. **Sulfur dioxide** (SO_2) is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. SO_2 is linked with a number of adverse effects on the respiratory system.
6. **Lead** is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in on-road motor vehicles (such as cars and trucks) and industrial sources. As a result of regulatory efforts in the U.S. to remove lead from on-road motor vehicle gasoline, emissions of lead from the transportation sector dramatically declined by 95 percent between 1980 and 1999, and levels of lead in the air decreased by 94 percent between 1980 and 1999. Today, the highest levels of lead in air are usually found near lead smelters. The major sources of lead emissions to the air today are ore and metals processing and piston-engine aircraft operating on leaded aviation gasoline.

Indoor Air Pollution (Major concerns in developed countries)

Most people spend approximately 90 percent of their time indoors. However, the indoor air we breathe in homes and other buildings can be more polluted than outdoor air and can increase the risk of illness. There are many sources of indoor air pollution in homes. They include biological contaminants such as bacteria, molds and pollen, burning of fuels and environmental tobacco smoke, building materials and furnishings, household products, central heating and cooling systems, and outdoor sources. Outdoor air pollution can enter buildings and become a source of indoor air pollution.

Sick building syndrome is a term used to describe situations in which building occupants have health symptoms that are associated only with spending time in that building. Causes of sick building syndrome are believed to include inadequate ventilation, indoor air pollution, and biological contaminants. Usually indoor air quality problems only cause discomfort. Most people feel better as soon as they remove the source of the pollution. Making sure that your building is well-ventilated and getting rid of pollutants can improve the quality of your indoor air.

Secondhand Smoke (Environmental Tobacco Smoke)

Secondhand smoke is the combination of smoke that comes from a cigarette and smoke breathed out by a smoker. When a non-smoker is around someone smoking, they breathe in secondhand smoke.

Secondhand smoke is dangerous to anyone who breathes it in. There is no safe amount of secondhand smoke. It contains over 7,000 harmful chemicals, at least 250 of which are known to damage human health. It can also stay in the air for several hours after somebody smokes. Even breathing secondhand smoke for a short amount of time can hurt your body.

Over time, secondhand smoke can cause serious health issues in non-smokers. The only way to fully protect non-smokers from the dangers of secondhand smoke is to not allow smoking indoors. Separating smokers from nonsmokers (like "no smoking" sections in restaurants), cleaning the air, and airing out buildings does not completely get rid of secondhand smoke.

Source: Smokefree.gov

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Page 13.2: Ozone Depletion

The ozone depletion process begins when **CFCs** (chlorofluorocarbons) and other ozone-depleting substances (ODS) are emitted into the atmosphere. CFC molecules are extremely stable, and they do not dissolve in rain. After a period of several years, ODS molecules reach the stratosphere, about 10 kilometers above the Earth's surface. CFCs were used by industry as refrigerants, degreasing solvents, and propellants.

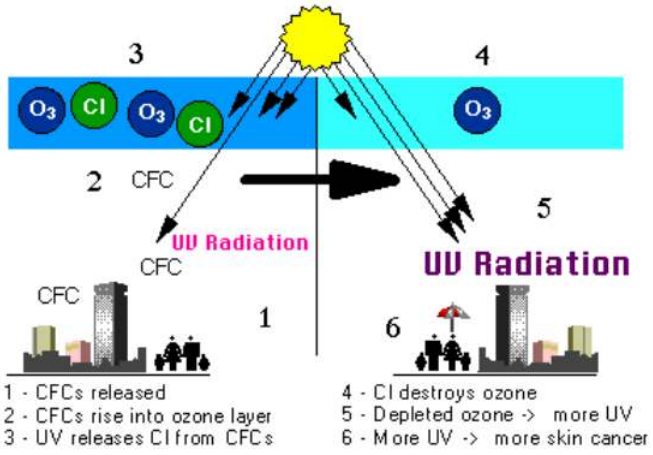


Figure $Page$13.2.1. Strong UV light breaks apart the ODS molecule. CFCs, HCFCs, carbon tetrachloride, methyl chloroform, and other gases release chlorine atoms, and halons and methyl bromide release bromine atoms. It is these atoms that actually destroy ozone, not the intact ODS molecule. It is estimated that one chlorine atom can destroy over 100,000 ozone molecules before it is removed from the stratosphere. Credit: NASA GSFC.

Ozone (O_3) is constantly produced and destroyed in a natural cycle, as shown in Figure $Page$13.2.1. However, the overall amount of ozone is essentially stable. This balance can be thought of as a stream's depth at a particular location. Although individual water molecules are moving past the observer, the total depth remains constant. Similarly, while ozone production and destruction are balanced, ozone levels remain stable. This was the situation until the past several decades. Large increases in stratospheric ODS, however, have upset that balance. In effect, they are removing ozone faster than natural ozone creation reactions can keep up. Therefore, ozone levels fall.

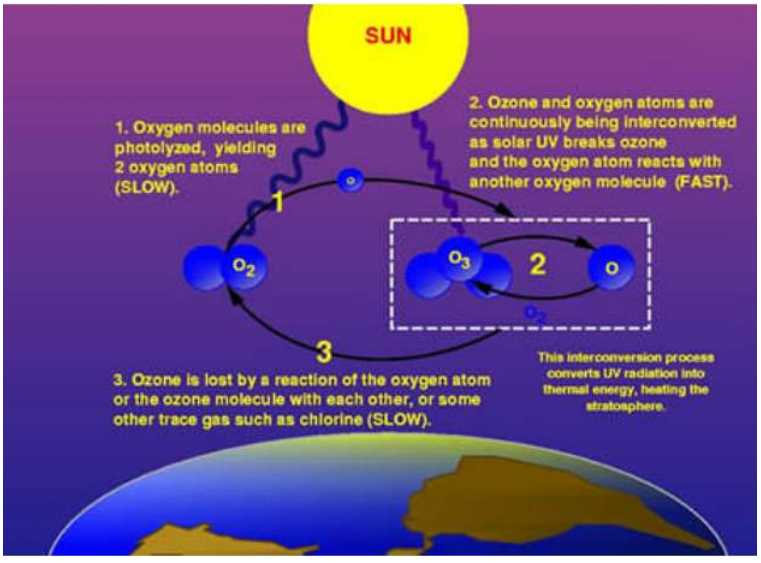


Figure $Page$13.2.2. Because ozone filters out harmful UVB radiation, less ozone means higher UVB levels at the surface. The more the depletion, the larger the increase in incoming UVB. UVB has been linked to skin cancer, cataracts, damage to materials like plastics, and harm to certain crops and marine organisms. Although some UVB reaches the surface even without ozone depletion, its harmful effects will increase as a result of this problem.

Policies to Reduce Ozone Destruction

One success story in reducing pollutants that harm the atmosphere concerns ozone-destroying chemicals. In 1973, scientists calculated that CFCs could reach the stratosphere and break apart. This would release chlorine atoms, which would then destroy ozone. Based only on their calculations, the United States and most Scandinavian countries banned CFCs in spray cans in 1978. More confirmation that CFCs break down ozone was needed before more was done to reduce production of ozone-destroying chemicals. In 1985, members of the British Antarctic Survey reported that a 50% reduction in the ozone layer had been found over Antarctica in the previous three springs.

Two years after the British Antarctic Survey report, the "Montreal Protocol on Substances that Deplete the Ozone Layer" was ratified by nations all over the world. The **Montreal Protocol**controls the production and consumption of 96 chemicals that damage the ozone layer (Figure *Page*13.2.3). CFCs have been mostly phased out since 1995, although they were used in developing nations until 2010. Some of the less hazardous substances will not be phased out until 2030. The Protocol also requires that wealthier nations donate money to develop technologies that will replace these chemicals.

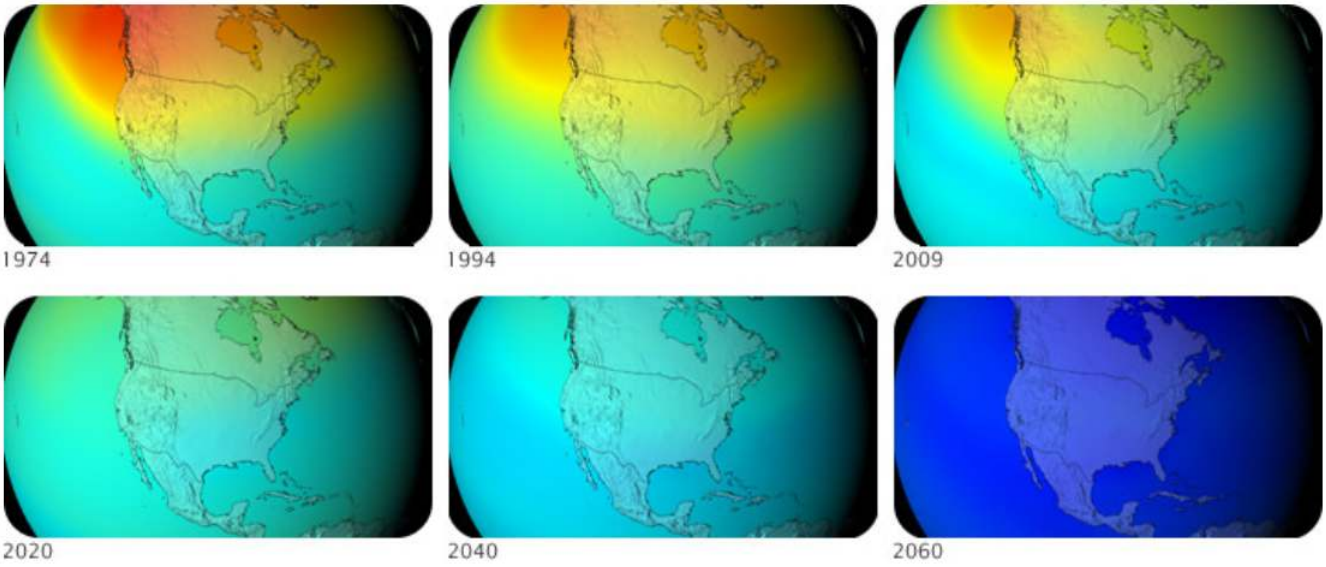


Figure *Page*13.2.3. Ozone levels over North America decreased between 1974 and 2009. Models of the future predict what ozone levels would have been if CFCs were not being phased out. Warmer colors indicate more ozone.

Because CFCs take many years to reach the stratosphere and can survive there a long time before they break down, the ozone hole will probably continue to grow for some time before it begins to shrink. The ozone layer will reach the same levels it had before 1980 around 2068 and 1950 levels in one or two centuries.

Health and Environmental Effects of Ozone Layer Depletion

There are three types of UV light: UVA, UVB, and UVC. Reductions in stratospheric ozone levels will lead to higher levels of UVB reaching the Earth's surface. The sun's output of UVB does not change; rather, less ozone means less protection, and hence more UVB reaches the Earth. Studies have shown that in the Antarctic, the amount of UVB measured at the surface can double during the annual ozone hole.

Laboratory and epidemiological studies demonstrate that UVB causes non-melanoma skin cancers and plays a major role in malignant melanoma development. In addition, UVB has been linked to cataracts, a clouding of the eye's lens. All sunlight contains some UVB, even with normal stratospheric ozone levels. Therefore, it is always important to protect your skin and eyes from the sun. Ozone layer depletion increases the amount of UVB and the risk of health effects.

UVB is generally harmful to cells, and therefore all organisms. UVB cannot penetrate into an organism very far and thus tends to only impact skin cells. Microbes like bacteria, however, are composed of only one cell and can therefore be harmed by UVB,

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Page 13.3: Acid Rain

Acid rain is a term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric and sulfuric acids. The precursors, or chemical forerunners, of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from fossil fuel combustion. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds. The result is a mild solution of sulfuric acid and nitric acid. When sulfur dioxide and nitrogen oxides are released from power plants and other sources, *prevailing winds* blow these compounds across state and national borders, sometimes over hundreds of miles.

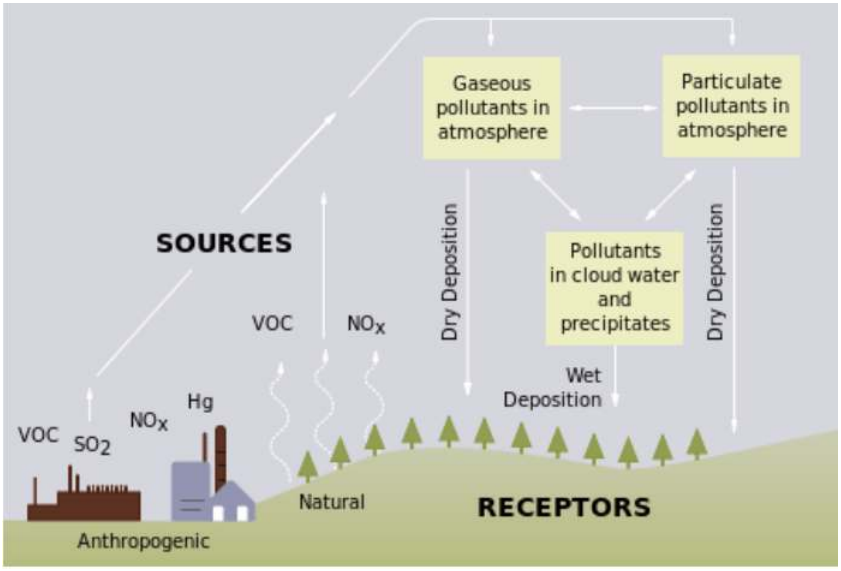


Figure $Page 13.3.1$. Processes involved in acid deposition.

Acid rain is measured using a scale called “pH.” The lower a substance’s pH, the more acidic it is. Pure water has a pH of 7.0. However, normal rain is slightly acidic because carbon dioxide (CO_2) dissolves into it forming weak carbonic acid, giving the resulting mixture a pH of approximately 5.6 at typical atmospheric concentrations of CO_2. As of 2000, the most acidic rain falling in the U.S. has a pH of about 4.3.

Effects of Acid Rain

Acid rain causes **acidification** of lakes and streams and contributes to the damage of trees at high elevations (for example, red spruce trees above 2,000 feet) and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation’s cultural heritage. Prior to falling to the earth, sulfur dioxide (SO_2) and nitrogen oxide (NO_x) gases and their particulate matter derivatives—sulfates and nitrates—contribute to visibility degradation and harm public health.

The **ecological** effects of acid rain are most clearly seen in the aquatic, or water, environments, such as streams, lakes, and marshes. Most lakes and streams have a pH between 6 and 8, although some lakes are naturally acidic even without the effects of acid rain. Acid rain primarily affects sensitive bodies of water, which are located in watersheds whose soils have a limited ability to neutralize acidic compounds (called “buffering capacity”). Lakes and streams become acidic (i.e., the pH value goes down) when the water itself and its surrounding soil cannot buffer the acid rain enough to neutralize it. In areas where buffering capacity is low, acid rain releases aluminum from soils into lakes and streams; aluminum is highly toxic to many species of aquatic organisms. Acid rain causes slower growth, injury, or death of **forests**. Of course, acid rain is not the only cause of such conditions. Other factors contribute to the overall stress of these areas, including air pollutants, insects, disease, drought, or very cold weather. In most cases, in fact, the impacts of acid rain on trees are due to the combined effects of acid rain and these other environmental stressors.


Figure $Page13.3.2$. A gargoyle that has been damaged by acid rain.

Acid rain and the dry deposition of acidic particles contribute to the corrosion of **metals**(such as bronze) and the deterioration of paint and stone (such as marble and limestone). These effects significantly reduce the societal value of buildings, bridges, cultural objects (such as statues, monuments, and tombstones), and cars (Figure $Page13.3.2$).

Sulfates and nitrates that form in the atmosphere from sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions contribute to **visibility impairment,** meaning we cannot see as far or as clearly through the air. The pollutants that cause acid rain—sulfur dioxide (SO_2) and nitrogen oxides (NO_x)—damage **human health**. These gases interact in the atmosphere to form fine sulfate and nitrate particles that can be transported long distances by winds and inhaled deep into people's lungs. Fine particles can also penetrate indoors. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis.

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Page 13.4: Climate Change

Earth's Temperature is a Balancing Act

Earth's temperature depends on the balance between energy entering and leaving the planet. When incoming energy from the sun is absorbed, Earth warms. When the sun's energy is reflected back into space, Earth avoids warming. When energy is released from Earth into space, the planet cools. Many factors, both natural and human, can cause changes in Earth's energy balance, including:

- Changes in the greenhouse effect, which affects the amount of heat retained by Earth's atmosphere;
- Variations in the sun's energy reaching Earth;
- Changes in the reflectivity of Earth's atmosphere and surface.

Scientists have pieced together a picture of Earth's climate, dating back hundreds of thousands of years, by analyzing a number of indirect measures of climate such as ice cores, tree rings, glacier size, pollen counts, and ocean sediments. Scientists have also studied changes in Earth's orbit around the sun and the activity of the sun itself.

The historical record shows that the climate varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations. Recent changes in climate**,** however, cannot be explained by natural causes alone. Research indicates that natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, it is extremely likely that human activities, especially our combustion of fossil fuels, explains most of that warming. The scientific consensus is clear: through alterations of the carbon cycle, humans are changing the global climate by increasing the effects of something known as the greenhouse effect.

The Greenhouse Effect Causes the Atmosphere to Retain Heat

Gardeners that live in moderate or cool environments use greenhouses because they trap heat and create an environment that is warmer than outside temperatures. This is great for plants that like heat, or are sensitive to cold temperatures, such as tomato and pepper plants. Greenhouses contain glass or plastic that allow visible light from the sun to pass. This light, which is a form of energy, is absorbed by plants, soil, and surfaces and heats them. Some of that heat energy is then radiated outwards in the form of infrared radiation, a different form of energy. Unlike with visible light, the glass of the greenhouse blocks the infrared radiation, thereby trapping the heat energy, causing the temperature within the greenhouse to increase.

The same phenomenon happens inside a car on a sunny day. Have you ever noticed how much hotter a car can get compared to the outside temperature? Light energy from the sun passes through the windows and is absorbed by the surfaces in the car such as seats and the dashboard. Those warm surfaces then radiate infrared radiation, which cannot pass through the glass. This trapped infrared energy causes the air temperatures in the car to increase. This process is commonly known as the **greenhouse effect**.

The greenhouse effect also happens with the entire Earth. Of course, our planet is not surrounded by glass windows. Instead, the Earth is wrapped with an atmosphere that contains **greenhouse gases** (GHGs). Much like the glass in a greenhouse, GHGs allow incoming visible light energy from the sun to pass, but they block infrared radiation that is radiated from the Earth towards space (Figure $Page13.4.1$). In this way, they help trap heat energy that subsequently raises air temperature. Being a greenhouse gas is a physical property of certain types of gases; because of their molecular structure they absorb wavelengths of infrared radiation, but are transparent to visible light. Some notable greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4).

GHGs act like a blanket, making Earth significantly warmer than it would otherwise be. Scientists estimate that average temperature on Earth would be -18º C without naturally-occurring GHGs.

What is Global Warming?
Global warming refers to the recent and ongoing rise in global average temperature near Earth's surface. It is caused mostly by increasing concentrations of greenhouse gases in the atmosphere. Global warming is causing climate patterns to change. However, global warming itself represents only one aspect of climate change.
What is Climate Change?
Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer.

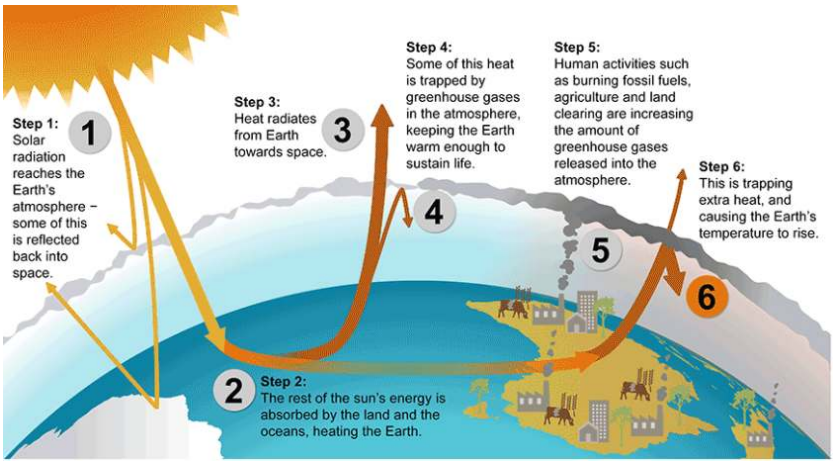


Figure $Page13.4.1$. Enhanced Greenhouse Effect

The Main Greenhouse Gasses

The most important GHGs directly emitted by humans include CO_2 and methane. **Carbon dioxide** (CO_2) is the primary greenhouse gas that is contributing to recent global climate change. CO_2 is a natural component of the carbon cycle, involved in such activities as photosynthesis, respiration, volcanic eruptions, and ocean-atmosphere exchange. Human activities, primarily the burning of fossil fuels and changes in land use, release very large amounts of CO_2 to the atmosphere, causing its concentration in the atmosphere to rise.

Atmospheric CO_2 concentrations have increased by 45% since pre-industrial times, from approximately 280 parts per million (ppm) in the 18th century to 408 ppm in 2018. The current CO_2 level is higher than it has been in at least 800,000 years, based on evidence from ice cores that preserve ancient atmospheric gases. Human activities currently release over 30 billion tons of CO_2 into the atmosphere every year.While some some volcanic eruptions released large quantities of CO_2 in the distant past, the U.S. Geological Survey (USGS) reports that human activities now emit more than 135 times as much CO_2 as volcanoes each year. This human-caused build-up of CO_2 in the atmosphere is like a tub filling with water, where more water flows from the faucet than the drain can take away.

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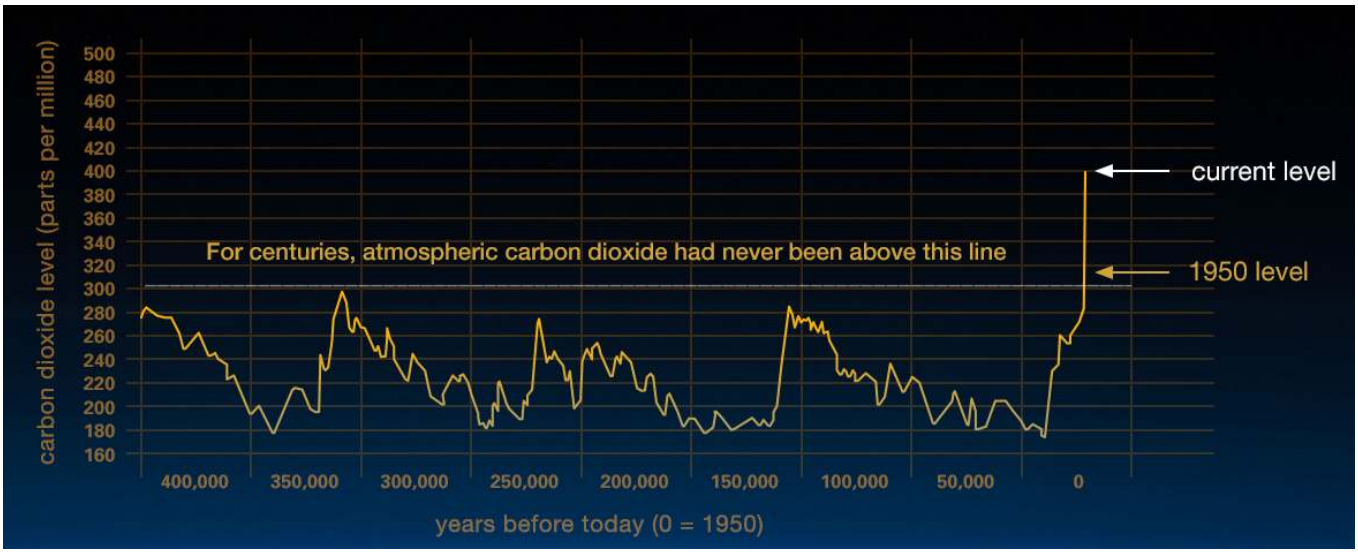


Figure $Page13.4.2$. This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record.)

Methane (CH_4) is produced through both natural and human activities. For example, wetlands, agricultural activities, and fossil fuel extraction and transport all emit CH_4. Methane is more abundant in Earth's atmosphere now than at any time in at least the past 650,000 years.Due to human activities, CH_4 concentrations increased sharply during most of the 20th century and are now more than two and-a-half times pre-industrial levels. In recent decades, the rate of increase has slowed considerably.

Other Greenhouse Gasses

Water vapor is the most abundant greenhouse gas and also the most important in terms of its contribution to the natural greenhouse effect, despite having a short atmospheric lifetime. Some human activities can influence local water vapor levels. However, on a global scale, the concentration of water vapor is controlled by temperature, which influences overall rates of evaporation and precipitation.Therefore, the global concentration of water vapor is not substantially affected by direct human emissions.

Ground-level ozone (O_3), which also has a short atmospheric lifetime, is a potent greenhouse gas. Chemical reactions create ozone from emissions of nitrogen oxides and volatile organic compounds from automobiles, power plants, and other industrial and commercial sources in the presence of sunlight (as discussed in section 10.1). In addition to trapping heat, ozone is a pollutant that can cause respiratory health problems and damage crops and ecosystems.

Changes in the Sun's Energy Affect how Much Energy Reaches Earth

Climate can be influenced by natural changes that affect how much solar energy reaches Earth. These changes include changes within the sun and changes in Earth's orbit. Changes occurring in the sun itself can affect the intensity of the sunlight that reaches Earth's surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity). The sun follows a natural 11-year cycle of small ups and downs in intensity, but the effect on Earth's climate is small.Changes in the shape of Earth's orbit as well as the tilt and position of Earth's axis can also affect the amount of sunlight reaching Earth's surface.

Changes in the sun's intensity have influenced Earth's climate in the past. For example, the so-called "**Little Ice Age**" between the 17th and 19th centuries may have been partially caused by a low solar activity phase from 1645 to 1715, which coincided with cooler temperatures. The Little Ice Age refers to a slight cooling of North America, Europe, and probably other areas around the globe. Changes in Earth's orbit have had a big impact on climate over tens of thousands of years. These changes appear to be the primary cause of past cycles of ice ages, in which Earth has experienced long periods of cold temperatures (ice ages), as well as shorter interglacial periods (periods between ice ages) of relatively warmer temperatures.

Changes in solar energy continue to affect climate. However, solar activity has been relatively constant, aside from the 11-year cycle, since the mid-20th century and therefore does not explain the recent warming of Earth. Similarly, changes in the shape of

Earth's orbit as well as the tilt and position of Earth's axis affect temperature on relatively long timescales (tens of thousands of years), and therefore cannot explain the recent warming.

Changes in Reflectivity Affect How Much Energy Enters Earth's System

When sunlight energy reaches Earth it can be reflected or absorbed. The amount that is reflected or absorbed depends on Earth's surface and atmosphere. Light-colored objects and surfaces, like snow and clouds, tend to reflect most sunlight, while darker objects and surfaces, like the ocean and forests, tend to absorb more sunlight. The term **albedo** refers to the amount of solar radiation reflected from an object or surface, often expressed as a percentage. Earth as a whole has an albedo of about 30%, meaning that 70% of the sunlight that reaches the planet is absorbed.Sunlight that is absorbed warms Earth's land, water, and atmosphere.

Albedo is also affected by aerosols. **Aerosols** are small particles or liquid droplets in the atmosphere that can absorb or reflect sunlight. Unlike greenhouse gases (GHGs), the climate effects of aerosols vary depending on what they are made of and where they are emitted. Those aerosols that reflect sunlight, such as particles from volcanic eruptions or sulfur emissions from burning coal, have a cooling effect. Those that absorb sunlight, such as black carbon (a part of soot), have a warming effect.

Natural changes in albedo, like the melting of sea ice or increases in cloud cover, have contributed to climate change in the past, often acting as feedbacks to other processes. Volcanoes have played a noticeable role in climate. Volcanic particles that reach the upper atmosphere can reflect enough sunlight back to space to cool the surface of the planet by a few tenths of a degree for several years.Volcanic particles from a single eruption do not produce long-term change because they remain in the atmosphere for a much shorter time than GHGs.

Human changes in land use and land cover have changed Earth's albedo. Processes such as deforestation, reforestation, desertification, and urbanization often contribute to changes in climate in the places they occur. These effects may be significant regionally, but are smaller when averaged over the entire globe.

Scientific Consensus: Global Climate Change is Real

The **Intergovernmental Panel on Climate Change** (IPCC) was created in 1988 by the United Nations Environment Programme and the World Meteorological Organization. It is charged with the task of evaluating and synthesizing the scientific evidence surrounding global climate change. The IPCC uses this information to evaluate current impacts and future risks, in addition to providing policymakers with assessments. These assessments are released about once every every six years. The most recent report, the 5th Assessment, was released in 2013. Hundreds of leading scientists from around the world are chosen to author these reports. Over the history of the IPCC, these scientists have reviewed thousands of peer-reviewed, publicly available studies. The scientific consensus is clear: global climate change is real and humans are very likely the cause for this change.

Additionally, the major scientific agencies of the United States, including the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), also agree that climate change is occurring and that humans are driving it. In 2010, the US National Research Council concluded that "Climate change is occurring, is very likely caused by human activities, and poses significant risks for a broad range of human and natural systems". Many independent scientific organizations have released similar statements, both in the United States and abroad. This doesn't necessarily mean that every scientist sees eye to eye on each component of the climate change problem, but broad agreement exists that climate change is happening and is primarily caused by excess greenhouse gases from human activities. Critics of climate change, driven by ideology instead of evidence, try to suggest to the public that there is no scientific consensus on global climate change. Such an assertion is patently false.

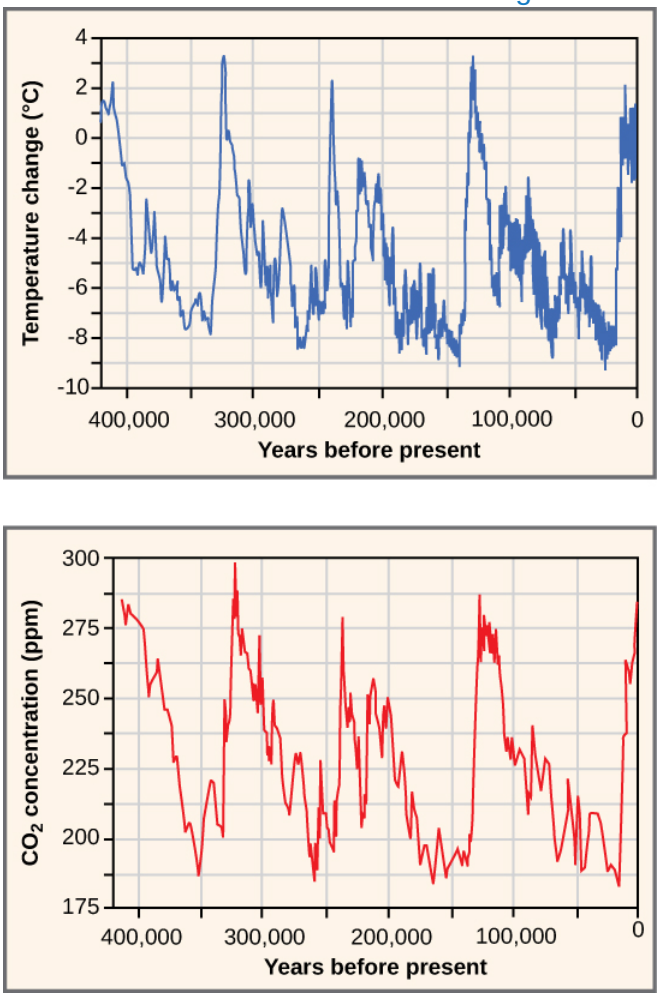


Figure $Page13.4.3$. Ice at the Russian Vostok station in East Antarctica was laid down over the course 420,000 years and reached a depth of over 3,000 m. By measuring the amount of CO_2 trapped in the ice, scientists have determined past atmospheric CO_2 concentrations. Temperatures relative to modern day were determined from the amount of deuterium (an isotope of hydrogen) present.

Greenhouse gas concentrations in the atmosphere will continue to increase unless the billions of tons of anthropogenic emissions each year decrease substantially. Increased concentrations are expected to:

- Increase Earth's average temperature,
- Influence the patterns and amounts of precipitation,
- Reduce ice and snow cover, as well as permafrost,
- Raise sea level,
- Increase the acidity of the oceans.

These changes will impact our food supply, water resources, infrastructure, ecosystems, and even our own health. The magnitude and rate of future climate change will primarily depend on the following factors:

- The rate at which levels of greenhouse gas concentrations in our atmosphere continue to increase,
- How strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected increase in greenhouse gas concentrations,
- Natural influences on climate (e.g., from volcanic activity and changes in the sun's intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns).

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Past and Present-day GHG Emissions Will Affect Climate Far into the Future

Many greenhouse gases stay in the atmosphere for long periods of time. As a result, even if emissions stopped increasing, atmospheric greenhouse gas concentrations would continue to remain elevated for hundreds of years. Moreover, if we stabilized concentrations and the composition of today's atmosphere remained steady (which would require a dramatic reduction in current greenhouse gas emissions), surface air temperatures would continue to warm. This is because the oceans, which store heat, take many decades to fully respond to higher greenhouse gas concentrations. The ocean's response to higher greenhouse gas concentrations and higher temperatures will continue to impact climate over the next several decades to hundreds of years.

Future Temperature Changes

Climate models project the following key temperature-related changes:

Key Global Projections

- Average global temperatures are expected to increase by 2°F to 11.5°F by 2100, depending on the level of future greenhouse gas emissions, and the outcomes from various climate models.
- By 2100, global average temperature is expected to warm at least twice as much as it has during the last 100 years.
- Ground-level air temperatures are expected to continue to warm more rapidly over land than oceans.
- Some parts of the world are projected to see larger temperature increases than the global average.

Future Precipitation and Storm Events

Patterns of precipitation and storm events, including both rain and snowfall are likely to change. However, some of these changes are less certain than the changes associated with temperature. Projections show that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may have more precipitation, and some may have little or no change. The amount of rain falling in heavy precipitation events is likely to increase in most regions, while storm tracks are projected to shift towards the poles. Climate models project the following precipitation and storm changes:

- Global average annual precipitation through the end of the century is expected to increase, although changes in the amount and intensity of precipitation will vary by region.
- The intensity of precipitation events will likely increase on average. This will be particularly pronounced in tropical and high-latitude regions, which are also expected to experience overall increases in precipitation.
- The strength of the winds associated with tropical storms is likely to increase. The amount of precipitation falling in tropical storms is also likely to increase.
- Annual average precipitation is projected to increase in some areas and decrease in others.

Future Ice, Snowpack, and Permafrost

Arctic sea ice is already declining drastically.The area of snow cover in the Northern Hemisphere has decreased since 1970.Permafrost temperature has increased over the last century, making it more susceptible to thawing.Over the next century, it is expected that sea ice will continue to decline, glaciers will continue to shrink, snow cover will continue to decrease, and permafrost will continue to thaw.

For every 2°F of warming, models project about a 15% decrease in the extent of annually averaged sea ice and a 25% decrease in September Arctic sea ice.The coastal sections of the Greenland and Antarctic ice sheets are expected to continue to melt or slide into the ocean. If the rate of this ice melting increases in the 21st century, the ice sheets could add significantly to global sea level rise.Glaciers are expected to continue to decrease in size. The rate of melting is expected to continue to increase, which will contribute to sea level rise.

Future Sea Level Change

Warming temperatures contribute to sea level rise by expanding ocean water, melting mountain glaciers and ice caps, and causing portions of the Greenland and Antarctic ice sheets to melt or flow into the ocean.Since 1870, global sea level has risen by about 8 inches. Estimates of future sea level rise vary for different regions, but global sea level for the next century is expected to rise at a greater rate than during the past 50 years.The contribution of thermal expansion, ice caps, and small glaciers to sea level rise is relatively well-studied, but the impacts of climate change on ice sheets are less understood and represent an active area of research.

Thus, it is more difficult to predict how much changes in ice sheets will contribute to sea level rise.Greenland and Antarctic ice sheets could contribute an additional 1 foot of sea level rise, depending on how the ice sheets respond.

Regional and local factors will influence future relative sea level rise for specific coastlines around the world. For example, relative sea level rise depends on land elevation changes that occur as a result of subsidence (sinking) or uplift (rising), in addition to things such as local currents, winds, salinity, water temperatures, and proximity to thinning ice sheets. Assuming that these historical geological forces continue, a 2-foot rise in global sea level by 2100 would result in the following relative sea level rise:

- 2.3 feet at New York City
- 2.9 feet at Hampton Roads, Virginia
- 3.5 feet at Galveston, Texas
- 1 foot at Neah Bay in Washington state

Future Ocean Acidification

Ocean acidification is theprocess of ocean waters decreasing in pH. Oceans become more acidic as carbon dioxide (CO_2) emissions in the atmosphere dissolve in the ocean. This change is measured on the pH scale, with lower values being more acidic. The pH level of the oceans has decreased by approximately 0.1 pH units since pre-industrial times, which is equivalent to a 25% increase in acidity. The pH level of the oceans is projected to decrease even more by the end of the century as CO_2 concentrations are expected to increase for the foreseeable future. Ocean acidification adversely affects many marine species, including plankton, mollusks, shellfish, and corals. As ocean acidification increases, the availability of calcium carbonate will decline. Calcium carbonate is a key building block for the shells and skeletons of many marine organisms. If atmospheric CO_2 concentrations double, coral calcification rates are projected to decline by more than 30%. If CO_2 concentrations continue to rise at their current rate, corals could become rare on tropical and subtropical reefs by 2050.

Spread of Disease

This rise in global temperatures will increase the range of disease-carrying insects and the viruses and pathogenic parasites they harbor. Thus, diseases will spread to new regions of the globe. This spread has already been documented with dengue fever, a disease the affects hundreds of millions per year, according to the World Health Organization. Colder temperatures typically limit the distribution of certain species, such as the mosquitoes that transmit malaria, because freezing temperatures destroy their eggs.

Not only will the range of some disease-causing insects expand, the increasing temperatures will also accelerate their lifecycles, which allows them to breed and multiply quicker, and perhaps evolve pesticide resistance faster. In addition to dengue fever, other diseases are expected to spread to new portions of the world as the global climate warms. These include malaria, yellow fever, West Nile virus, zika virus, and chikungunya.

Climate change affects everyone

Our lives are connected to the climate**.** Human societies have adapted to the relatively stable climate we have enjoyed since the last ice age which ended several thousand years ago. A warming climate will bring changes that can affect our water supplies, agriculture, power and transportation systems, the natural environment, and even our own health and safety.

Carbon dioxide can stay in the atmosphere for nearly a century, on average, so Earth will continue to warm in the coming decades. The warmer it gets, the greater the risk for more severe changes to the climate and Earth's system. Although it's difficult to predict the exact impacts of climate change, what's clear is that the climate we are accustomed to is no longer a reliable guide for what to expect in the future.

We can reduce the risks we will face from climate change**.** By making choices that reduce greenhouse gas pollution, and preparing for the changes that are already underway, we can reduce risks from climate change. Our decisions today will shape the world our children and grandchildren will live in.

You Can Take Action

You can take steps at home, on the road, and in your office to reduce greenhouse gas emissions and the risks associated with climate change. Many of these steps can save you money. Some, such as walking or biking to work, can even improve your health! You can also get involved on a local or state level to support energy efficiency, clean energy programs, or other climate programs.

Suggested Supplementary Reading:

Intergovernmental Panel on Climate Change. 2013. 5th Assessment: Summary for Policymakers. <http://www.ipcc.ch/pdf/assessment-re..._SPM_FINAL.pdf>

NASA. 2018. Global Climate Change: Vital Signs of the Planet. Website. <https://climate.nasa.gov/>

This website by NASA provides a multi-media smorgasbord of engaging content. Learn about climate change using data collected by NASA satellites and more.

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Page 13.5: Chapter Resources

Summary

Air pollution can be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Chemicals discharged into the air that have a direct impact on the environment are called primary pollutants. These primary pollutants sometimes react with other chemicals in the air to produce secondary pollutants. The commonly found air pollutants, known as criteria pollutants, are particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants can harm health and the environment, and cause property damage. The historical record shows that the climate system varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas concentrations. Recent climate changes, however, cannot be explained by natural causes alone. Natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, human activities can explain most of that warming.

The primary human activity affecting the amount and rate of climate change is greenhouse gas emissions from the burning of fossil fuels. Greenhouse gas concentrations in the atmosphere will continue to increase unless the billions of tons of our annual emissions decrease substantially. Increased concentrations are expected to increase Earth's average temperature, influence the patterns and amounts of precipitation, reduce ice and snow cover, as well as permafrost, raise sea level and increase the acidity of the oceans. These changes will impact our food supply, water resources, infrastructure, ecosystems, and even our own health. Acid rain is a term referring to a mixture of wet and dry deposition from the atmosphere containing higher than normal amounts of nitric and sulfuric acids. The precursors of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx) resulting from fossil fuel combustion. Acid rain causes acidification of lakes and streams, contributes to the damage of trees and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, contributes to the corrosion of metals and damages human health. The ozone depletion process begins when CFCs and other ozone-depleting substances (ODS) are emitted into the atmosphere. Reductions in stratospheric ozone levels lead to higher levels of UVB reaching the Earth's surface. The sun's output of UVB does not change; rather, less ozone means less protection, and hence more UVB reaches the Earth. Ozone layer depletion increases the amount of UVB tat lead to negative health and environmental effects.

Review Questions

1. Ground-level ozone…
   A. Protects us from radiation
   B. Is a primary pollutant
   C. Is a secondary pollutant
   D. Reduces visibility but is mostly harmless to human health
   E. Is emitted from motor vehicles
2. Secondary pollutants are pollutants…
   A. Emitted from non-point sources
   B. That are created from the reaction of primary pollutants and other chemicals
   C. That are less hazardous than primary pollutants
   D. That have reduced ability to stay aloft in the atmosphere
   E. Emitted by Class 2 polluters
3. Depletion of the stratospheric ozone layer occurs when molecules of ozone are destroyed by chemicals such as…
   A. CFC
   B. DDT
   C. O_3
   D. PCB
   E. CH_4
4. What is the function of the stratospheric ozone layer?

A. Provides the biosphere with a source of elemental oxygen
B. Protects against ultraviolet light
C. Shields the Earth from high-energy cosmic rays
D. Protects organisms from infrared radiation
E. Creates UVB radiation for vitamin D synthesis

5. Anthropogenic causes of acid rain are primarily due to which one of the following?
   A. Destruction of the ozone layer
   B. Emissions of sulfur dioxide and nitrogen oxides from the combustion of fossil fuels
   C. Emissions of carbon dioxide from the combustion of fossil fuels
   D. Industrial emissions of acids
   E. Acids formed in the contrails of airplanes
6. The scientific consensus regarding global climate change is that these changes are…
   A. Caused by natural, Earth-based phenomena such as volcanoes
   B. Poorly understood and no scientific conclusions can be made at this time
   C. Primarily caused by human activities
   D. Caused by eccentricity in Earth's orbit and by changes in solar intensity
   E. No greater or different than changes seen in the medieval times
7. Greenhouse gases are known to raise air temperatures by…
   A. absorbing infrared radiation
   B. creating heat through chemical reactions with atmospheric pollutants
   C. absorbing incoming visible light from the sun
   D. trapping high energy molecules and atomic particles
   E. releasing heat stored in high-altitude catalytic cycles
8. Changes in reflectivity of visible light affect how much energy enters Earth's system. What term is used by scientists to describe the reflectivity of a surface?
   A. Contrastivity
   B. Libido
   C. Mirror-effect
   D. Alluvium
   E. Albedo
9. What is the primary cause of ocean acidification?
   A. Atmospheric CO2 dissolving in ocean water
   B. Increases in acid rain
   C. Increased erosion of acid-containing rocks
   D. Water draining into the ocean has a higher pH from industrial pollutants
   E. All of the above
10. Which one of the following is not a predicted consequence of global climate change?
    A. Spread of diseases carried by insects, such as malaria
    B. Rise in sea levels
    C. Increases in the global average air and ocean temperatures
    D. Intensity of precipitation events will likely increase on average.
    E. All of the above

See Appendix for answers

Attributions

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CHAPTER OVERVIEW

14: Sustainability - Ethics, Culture, and History

Page 14.1: The Human Dimensions of Sustainability- History, Culture, Ethics

Page 14.2: It’s Not Easy Being Green- Anti-Environmental Discourse, Behavior, and Ideology

Page 14.3: The Industrialization of Nature- A Modern History (1500 to the present)

Page 14.4: Case Study- Agriculture and the Global Bee Colony Collapse

Page 14.5: Sustainability Ethics

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Page 14.1: The Human Dimensions of Sustainability- History, Culture, Ethics



Figure *Page*14.1.1 Earth day

Once we begin talking about sustainability, it's hard to stop. That's because sustainability is truly the science of everything, from technical strategies for repowering our homes and cars, to the ecological study of biodiversity in forests and oceans, to how we think and act as human beings. This latter category—the "human dimensions" of sustainability—is the focus of this chapter. Much sustainability discourse focuses on scientific, technical and regulatory issues, but there is increasing awareness that without changes in people's attitudes and patterns of behavior, and how these attitudes are reflected in public policymaking priorities, meaningful reform toward a more sustainable management of natural resources will be impossible. One key to this problem is that we are accustomed to thinking of the environment as a remote issue. Even the words "environment" and "nature" themselves suggest the habitual view we take of ourselves as somehow independent of or superior to the planet's material resources and processes. The truth is different. Humanity is but a thread of nature's web, albeit an original and brilliant thread. So brilliant indeed that we are now shaping the evolution of the web itself, to our short-term advantage, but in ways that cannot be sustained.

One example of the centrality of the human dimensions component of sustainability studies is the fact that sustainable technologies of food and energy production are increasingly available, but have yet to be adapted on the necessary scale to make a difference to humanity's overall environmental footprint on the planet. Many look to technology for answers to our myriad environmental problems, but the fact that even the limited technological innovations that exist lack support and have been inadequately deployed is a complex human issue, touching an essential resistance to change in our economic and political structures, our lifestyles and culture and, at the micro-level, basic human psychology and behavior. This chapter will explore these human dimensions of the sustainability challenge, with an emphasis on the historical and cultural factors that have placed us on our dangerously unsustainable path, and which make changing course so challenging.

Sustainability in human terms is, first and foremost, a commonsense goal: to ensure that conditions on earth continue to support the project of human civilization, that widely diverse populations of the global community not slip into protracted crisis on account of deteriorating environmental conditions and depleted resources. This preventive dimension of sustainability discourse inevitably involves doom projections. Despite the popularity of apocalyptic, end-of-the-world scenarios in Hollywood movies, science fiction, and some corners of the blogosphere, the biological end of the human race remains scarcely imaginable—we will continue on, in some form. But in the emerging perfect storm of food stock declines, water scarcity, climate disruption, and energy shortfalls, there now exist measurable global-scale threats to social order and basic living standards that are the material bedrock of civic society as we recognize it.

The dramatic environmental changes underway on earth are already impacting human social systems. Droughts, floods, and rising sea levels are taking lives, damaging infrastructure, reducing crop yields and creating a new global underclass of environmental refugees. The question is how much more serious will these impacts become and how soon? There are no reassuring answers if we continue on a business-as-usual path. One thing about sustainability in the twenty-first century is certain: individual nations and the international community together will need to both mitigate the projected declines of the planet's ecosystems, and at the same time adapt to those that are irreversible. As one popular sustainability policy mantra has it: "we must strive to avoid the unmanageable, while managing the unavoidable."

The environmental historian Sing Chew sees in the cluster of environmental crises of the early 21st century the hallmarks of a potential new Dark Age, that is, a period of conflict, resource scarcity and cultural impoverishment such as has afflicted the global human community only a few times over the past five millennia. The goal of sustainability, in these terms, is clear and non-controversial: to avoid a new and scaled-up Dark Age in which the aspirations of billions of people, both living and yet unborn, face brutal constraints. The implications of sustainability, in this sense, extend well beyond what might ordinarily considered "green" issues, such as preserving rainforests or saving whales. Sustainability is a human and social issue as much as it is "environmental." Sustainability is about people, the habitats we depend on for services vital to us, and our ability to maintain culturally rich civic societies free from perennial crises in food, water, and energy supplies.

Glossary

Adaptation

Focuses on the need for strategies to deal with the climate change that is unavoidable because of increased carbon already in the atmosphere

Mitigation

Refers to the importance of reducing carbon emissions so as to prevent further, catastrophic changes in the climate system.

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Page 14.2: It's Not Easy Being Green- Anti-Environmental Discourse, Behavior, and Ideology

Introduction

The consensus view among scientists and professional elites in the early twenty-first century, as it has been among environmental activists for a much longer time, is that our globalized industrial world system is on an unsustainable path. Inherent in this view is a stern judgment of the recent past: we have not adapted well, as a species, to the fruits of our own brilliant technological accomplishments, in particular, to the harnessing of fossil fuels to power transport and industry.

Taking the long view of human evolution, it is not surprising to find that we are imperfectly adapted to our modern industrialized world of cars, computers, and teeming cities, or that human societies organized for so many millennia around the problem of scarcity should treat a sudden abundance of resources with the glee of a kid in a candy store. In evolutionary terms, we have simply not had sufficient time to adapt to the windfall of change. Though rapid advances in the biophysical sciences in recent decades mean that we mostly understandour maladaptation to industrialization and the great dangers it poses, our political decision-making and consumption patterns have barely changed on the basis of this understanding. This sobering fact tells us that, at this moment in human history, social behavior and political decision-making are not being driven by knowledge, but rather by entrenched attitudes that perpetuate an unsustainable drawdown of earth's resources. In short, human decision making and consumption of material goods in our fossil-fuel age continues to largely take place outside of an awareness of the strained and finite nature of our planet's ecosystem services.

It is the character of modern consumer society to promote the idea that nothing is connected, that the jeans we wear, or the food we eat, are matters of personal choice without any greater context beyond a concern for immediate pleasure and peer approval. Sustainability, by contrast, teaches that everything is connected. That favorite pair of jeans, for instance, is dependent on cheap labor in developing countries, on heavily fertilized cotton plantations, and enormous volumes of water expended throughout the jeans' lifecycle, from the irrigation to grow the cotton to the washing machine that cleans them. Or let's take that "cheap" fast food lunch from yesterday: it most likely contained processed soybeans from a recently cleared stretch of the Amazon rainforest, and artificial sweeteners made from corn whose enormous production quotas are subsidized by government tax revenues. The corn-based sweetener, in turn, turns out to be a principal cause of the national obesity epidemic, a key contributor to spiraling health care costs. Thus the "value meal" turns out not to be so economical after all, once the systems-wide effects are factored in.

A twenty minute video, The Story of Stuff, tells the complicated story of how our "stuff" moves from extraction to sale to disposal.



Figure *Page*14.2.2 Fast Food Industry's Environmental Impact? Here's food for thought. Though we are accustomed to measuring the impact of a fast food diet on our physical health, there is much less readily available information on the global network of agricultural providers that supports the fast food industry, and on its environmental impacts on land use, water resources, and human communities. Source: Created by CrazyRob926

Connectivity

To think about sustainability in these terms may sound exhausting. But because we live in a world characterized by connectivity, that is, bycomplex chains linking our everyday lives to distant strangers and ecosystems in far flung regions of the earth, we have no choice. In the end, we must adapt our thinking to a complex, connected model of the world and our place in it. Persisting with only simple, consumerist frames of understanding—"I look great!" "This tastes delicious!"—for a complex world of remote impacts and finite resources renders us increasingly vulnerable to episodes of what ecologists call system collapse, that is, to the sudden breakdown of ecosystem services we rely upon for our life's staple provisions.

In the early twenty-first century, vulnerability to these system collapses varies greatly according to where one lives. A long-term drought in India might bring the reality of aquifer depletion or climate change home to tens of thousands of people driven from their land, while the life of a suburban American teenager is not obviously affected by any resource crisis. But this gap will narrow in the coming years. Overwhelming scientific evidence points to rapidly increasing strains this century on our systems of food, water, and energy provision as well as on the seasonable weather to which we have adapted our agricultural and urban regions. In time, no one will enjoy the luxury of remaining oblivious to the challenges of sustainability. Drought, for example, is one of the primary indices of global ecosystem stress, and arguably the most important to humans. According to the United Nations Food and

Agriculture Organization, without wholesale reformation of water management practices on a global scale, two-thirds of the world's population will face water shortages by 2025, including densely populated regions of the United States.

So how did we arrive at this point? Without you or I ever consciously choosing to live unsustainably, how has it nevertheless come about that we face environmental crises of global scale, circumstances that will so decisively shape our lives and those of our children? Here's one explanatory narrative, framed by the long view of human evolution.

Since the emergence of the first proto-human communities in Africa millions of years ago, we have spent over 99% of evolutionary time as nomadic hunters and gatherers. A fraction of the balance of our time on earth spans the 10,000 years of human agriculture, since the end of the last Ice Age. In turn, only a third of that fractional period has witnessed the emergence of the institutions and technologies—writing, money, mathematics, etc.—that we associate with human "civilization." And lastly, at the very tip of the evolutionary timeline, no more than a blink of human species history, we find the development of the modern industrialized society we inhabit. Look around you. Observe for a moment all that is familiar in your immediate surroundings: the streetscape and buildings visible through the window, the plastic furnishings in the room, and the blinking gadgets within arm's length of where you sit. All of it is profoundly "new" to human beings; to all but a handful of the tens of thousands of generations of human beings that have preceded us, this everyday scene would appear baffling and frightening, as if from another planet.

Normalization

In this sense, the real miracle of human evolution is that cars, computers, and cities appear so normal to us, even sometimes "boring" and monotonous! Our perception of the extraordinary, rapid changes in human societies in the past two centuries—even the past half-century—is deadened by virtue of what is our greatest evolutionary acquirement, namely normalization, an adaptive survival strategy fundamental to human success over the millennia. The ability to accept, analyze, and adapt to often fluctuating circumstances is our great strength as a species. But at this point in human history it is also a grave weakness, what, in the language of Greek tragedy might be called a "fatal flaw."

To offer an analogy, for many centuries slavery appeared normal to most people across the world—until the late eighteenth century, when a handful of humanitarian activists in Britain began the long and difficult process of de-normalizing human bondage in the eyes of their compatriots. The task of sustainability ethics is analogous, and no less difficult, in that it lays out the argument for wholesale and disruptive attitude adjustment and behavior change in the general population. Given the long-term adaptation of the human species to the imperatives of hunter-gathering, our decision-making priorities and consumption drives still tend toward the simple necessities, based on the presumption of relative and seasonal scarcity, and with little emotional or social reward for restraint in the face of plenty, for viewing our choices in global terms, or for measuring their impacts on future generations.

A working distinction between the historical evolution of human *society* and human *culture* is useful to understanding the social and psychological obstacles to achieving sustainability. As both individuals and societies, we work hard to insulate ourselves from unpleasant surprises, shocks, and disorder. We crave "security," and our legal and economic institutions accordingly have evolved over the millennia to form a buffer against what Shakespeare's Hamlet called "the thousand natural shocks that flesh is heir to." For instance, the law protects us from violent physical harm (ideally), while insurance policies safeguard us from financial ruin in the event of an unexpected calamity.

In one sense, this security priority has determined the basic evolution of human societies, particularly the decisive transition 10,000 years ago from the variable and risky life of nomadic hunter communities to sedentary farming based on an anticipated stability of seasonal yields. Of course, the shift to agriculture only partially satisfied the human desire for security as farming communities remained vulnerable to changing climatic conditions and territorial warfare. Global industrialization, however, while it has rendered vast populations marginal and vulnerable, has offered its beneficiaries the most secure insulation yet enjoyed by humans against "the slings and arrows of outrageous fortune." This success has been a double-edged sword, however, not least because the industrialized cocoon of our modern consumer lifestyles relentlessly promotes the notion that we have transcended our dependence on the earth's basic resources. As it stands, we look at our highly complex, industrialized world, and adapt our expectations and desires to its rewards. It is never our first instinct to ask whether the system of rewards itself might be unsustainable and collapse at some future time as a result of our eager participation.

Sustainability Obstacles and Support

In terms of the evolutionary argument I am outlining here, our ability to grasp the sustainability imperative faces two serious obstacles. The first is psychological, namely the inherited mental frameworks that reward us for the normalization and simplification of complex realities. The second is social, namely our economic and institutional arrangements designed to protect us from material wants, as well as from risk, shock, disorder and violent change. Both these psychological and social features of our lives militate against an ecological, systems-based worldview.

Luckily, our *cultural* institutions have evolved to offer a counterweight to the complacency and inertia encouraged by the other simple, security-focused principles governing our lives. If society is founded upon the principle of security, and promotes our complacent feeling of independence from the natural world, we might think of culture as the conscience of society. What culture does, particularly in the arts and sciences, is remind us of our frailty as human beings, our vulnerability to shocks and sudden changes, and our connectedness to the earth's natural systems. In this sense, the arts and sciences, though we conventionally view them as opposites, in fact perform the same social function: they remind us of what lies beyond the dominant security paradigm of our societies—which tends to a simplified and binary view of human being and nature—by bringing us closer to a complex, systemic understanding of how the natural world works and our embeddedness within it. Whether by means of an essay on plant biology, or a stage play about family breakdown (like *Hamlet*), the arts and sciences model complex worlds and the systemic interrelations that shape our lives. They expose complexities and connectivities in our world, and emphasize the material consequences of our actions to which we might otherwise remain oblivious. The close relation between the arts and sciences in the Western world is evidenced by the fact that their concerns have largely mirrored each other over time, from the ordered, hierarchical worldview in the classical and early modern periods, to the post-modern focus on connectivity, chaos, and emergence.

Life in the pre-modern world, in the memorable words of the English philosopher Thomas Hobbes, was mostly "nasty, brutish, and short." By contrast, social and economic evolution has bestowed the inhabitants of the twenty-first century industrialized world with a lifestyle uniquely (though of course not wholly) insulated from physical hardship, infectious disease, and chronic violence. This insulation has come at a cost, however, namely our disconnection from the basic support systems of life: food, water and energy. This is a very recent development. At the beginning of the 20th century, for example, almost half of Americans grew up on farms. Now, fewer than two percent do. We experience the staples of life only at their service endpoints: the supermarket, the faucet, the gas station. In this context, the real-world sources of food, water, and energy do not seem important, while supplies appear limitless. We are not prepared for the inevitable shortages of the future.

On the positive side, it is possible to imagine that the citizens of the developed world might rapidly reconnect to a systems view of natural resources. One product of our long species evolution as hunters and agricultural land managers is an adaptive trait the ecologist E. O. Wilson has called "biophilia," that is, a love for the natural world that provides for us. In the few centuries of our fossil fuel modernity, this biophilia has become increasingly aestheticized and commodified—as landscape art, or nature tourism—and consequently marginalized from core social and economic decision structures. In the emerging age of environmental decline and resource scarcity, however, our inherited biophilia will play a key role in energizing the reform of industrialized societies toward a sustainable, renewable resource and energy future.

Review Questions

1. How has the human capacity for *normalization* both helped and hindered social development, and what are its implications for sustainable reform of our industries, infrastructure, and way of life?
2. Take an everyday consumer item—running shoes, or a cup of coffee—and briefly chart its course through the global consumer economy from the production of its materials to its disposal. What are its environmental impacts, and how might they be reduced?

Glossary

Connectivity

An important feature of complex systems. Connections exist between even apparently remote and disparate things. For example, drought in Australia might impact the price of bread in Egypt, which in turn has repercussions for U.S. foreign policy.

Normalization

An acquired evolutionary trait characteristic of human beings, whereby even radical changes are quickly adapted to and represented as normal.

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Page 14.3: The Industrialization of Nature- A Modern History (1500 to the present)

Introduction

It is a measure of our powers of normalization that we in the developed world take the existence of cheap energy, clean water, abundant food, and international travel so much for granted, when they are such recent endowments for humanity, and even now are at the disposal of considerably less than half the global population. It is a constant surprise to us that a situation so "normal" could be having such abnormal effects on the biosphere—degrading land, water, air, and the vital ecosystems hosting animals and fish. How did we get here? How can we square such apparent plenty with warnings of collapse?

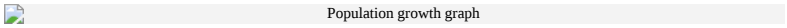


Figure *Page*14.3.1 Graph showing the rapid increase in human population since the beginning of the Industrial Age, with exponential rise since the mid-twentieth century. Source: IGBP synthesis: Global Change and the Earth System, Steffen et al 2004

Raw figures at least sketch the proportions of global change over the last 500 years. In 1500, even after several centuries of rapid population growth, the global population was no more than 500 million, or less than half the population of India today. It is now fourteen times as large, almost 7 billion. Over the same period, global economic output has increased 120 times, most of that growth occurring since 1820, and with the greatest acceleration since 1950. This combination of rampant population and economic growth since 1500 has naturally had major impacts on the earth's natural resources and ecosystem health. According to the United Nations Millennium Ecosystem Assessment, by the beginning of the 21st century, 15 of the world's 24 ecosystems, from rainforests to aquifers to fisheries, were rated in serious decline.

Economic Development

Fundamental to significant changes in human history has been social reaction to resource scarcity. By 1500, Europeans, the first engineers of global growth, had significantly cleared their forests, settled their most productive agricultural lands, and negotiated their internal borders. And yet even with large-scale internal development, Europe struggled to feed itself, let alone to match the wealth of the then dominant global empires, namely China and the Mughal States that stretched from the Spice Islands of Southeast Asia to the busy ports of the Eastern Mediterranean. As a consequence of resource scarcity, European states began to sponsor explorations abroad, in quest initially for gold, silver, and other precious metals to fill up their treasuries. Only over time did Europeans begin to perceive in the New World the opportunities for remote agricultural production as a source of income. Full-scale colonial settlement was an even later idea.

The new "frontiers" of European economic development in the immediate pre-industrial period 1500-1800 included tropical regions for plantation crops, such as sugar, tobacco, cotton, rice, indigo, and opium, and temperate zones for the cultivation and export of grains. The seagoing merchants of Portugal, France, Spain, Britain and the Netherlands trawled the islands of the East Indies for pepper and timber; established ports in India for commerce in silk, cotton and indigo; exchanged silver for Chinese tea and porcelain; traded sugar, tobacco, furs and rice in the Americas; and sailed to West Africa for slaves and gold. The slave trade and plantation economies of the Americas helped shift the center of global commerce from Asia to the Atlantic, while the new oceangoing infrastructure also allowed for the development of fisheries, particularly the lucrative whale industry. All these commercial developments precipitated significant changes in their respective ecosystems across the globe—deforestation and soil erosion in particular—albeit on a far smaller scale compared with what was to come with the harnessing of fossil fuel energy after 1800.

The 19th century witnessed the most rapid global economic growth seen before or mostly since, built on the twin tracks of continued agricultural expansion and the new "vertical" frontiers of fossil fuel and mineral extraction that truly unleashed the transformative power of industrialization on the global community and its diverse habitats. For the first time since the human transition to agriculture more than 10,000 years before, a state's wealth did not depend on agricultural yields from contiguous lands, but flowed rather from a variety of global sources, and derived from the industrialization of primary products, such as cotton textiles, minerals and timber. During this period, a binary, inequitable structure of international relations began to take shape, with a *core* of industrializing nations in the northern hemisphere increasingly exploiting the natural resources of undeveloped *periphery* nations for the purposes of wealth creation.



Figure $Page14.3.2$ Trade Map, Late 20th Century. This map shows the "core" industrialized nations of the northern hemisphere, and the "periphery" nations of the tropics and south dependent on subsistence agriculture and natural resource extraction. This unequal relationship is the product of hundreds of years of trade and economic globalization Source: Created by Naboc1, based on a list in Christopher Chase-Dunn, Yukio Kawano and Benjamin Brewer, Trade Globalization since 1795, American Sociological Review, 2000 February, Vol. 65

The Great Acceleration

Despite the impact of the world wars and economic depression on global growth in the early 20th century, the new technological infrastructure of the combustion engine and coal-powered electricity sponsored increased productivity and the sanitization of growing urban centers. Infectious diseases, the scourge of humanity for thousands of years, retreated, more than compensating for losses in war, and the world's population continued to increase dramatically, doubling from 1 to 2 billion in 50 years, and with it the ecological footprint of our single species.

Nothing, however, is to be compared with the multiplying environmental impacts of human activities since 1950, a period dubbed by historians as "The Great Acceleration." In the words of the United Nations Millennium Ecosystem Assessment, "over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth." The post-WWII global economic order promoted liberal and accelerated trade, capital investment, and technological innovation tethered to consumer markets, mostly free of environmental impact considerations. The resultant economic growth, and the corresponding drawdown of natural resources, are nonlinear in character, which is, exhibiting an unpredictable and exponential rate of increase.

All systems, human and natural, are characterized by nonlinear change. We are habituated to viewing our history as a legible story of "progress," governed by simple cause-and-effect and enacted by moral agents, with the natural world as a backdrop to scenes of human triumph and tragedy. But history, from a sustainability viewpoint, is ecological rather than dramatic or moral; that is, human events exhibit the same patterns of systems connectivity, complexity, and non-linear transformation that we observe in the organic world, from the genetic makeup of viruses to continental weather systems. The history of the world since 1950 is one such example, when certain pre-existing conditions—petroleum-based energy systems, technological infrastructure, advanced knowledge-based institutions and practices, and population increase—synergized to create a period of incredible global growth and transformation that could not have been predicted at the outset based upon those conditions alone. This unforeseen Great Acceleration has brought billions of human beings into the world, and created wealth and prosperity for many. But nonlinear changes are for the bad as well as the good, and the negative impacts of the human "triumph" of postwar growth have been felt across the biosphere. I will briefly detail the human causes of the following, itself only a selective list: soil degradation, deforestation, wetlands drainage and damming, air pollution and climate change.

Soil Degradation

Since the transition to agriculture 10,000 years ago, human communities have struggled against the reality that soil suffers nutrient depletion through constant plowing and harvesting (mostly nitrogen loss). The specter of a significant die-off in human population owing to stagnant crop yields was averted in the 1970s by the so-called "Green Revolution," which, through the engineering of new crop varieties, large-scale irrigation projects, and the massive application of petroleum-based fertilizers to supplement nitrogen, increased staple crop production with such success that the numbers suffering malnutrition actually declined worldwide in the last two decades of the 20th century, from 1.9 to 1.4 billion, even as the world's population increased at 100 times background rates, to 6 billion. The prospects for expanding those gains in the new century are nevertheless threatened by the success of industrial agriculture itself. Soil depletion, declining water resources, and the diminishing returns of fertilizer technology—all the products of a half-century of industrial agriculture—have seen increases in crop yields level off. At the same time, growing populations in developing countries have seen increasing clearance of fragile and marginal agricultural lands to house the rural poor.

It has been estimated that industrial fertilizers have increased the planet's human carrying capacity by two billion people. Unfortunately, most of the chemical fertilizer applied to soils does not nourish the crop as intended, but rather enters the hydrological system, polluting aquifers, streams, and ultimately the oceans with an oversupply of nutrients, and ultimately draining the oxygen necessary to support aquatic life. As for the impact of fertilizers on soil productivity, this diminishes over time, requiring the application of ever greater quantities in order to maintain yields.

Deforestation

Arguably the biggest losers from 20th century economic growth were the forests of the world's tropical regions and their non-human inhabitants. Across Africa, Asia, and the Americas, approximately one-third of forest cover has been lost. Because about half of the world's species inhabits tropical rainforests, these clearances have had a devastating impact on biodiversity, with extinction rates now greater than they have been since the end of the dinosaur era, 65 million years ago. Much of the cleared land was converted to agriculture, so that the amount of irrigated soils increased fivefold over the century, from 50 to 250m hectares. Fully 40% of the terrestrial earth's total organic output is currently committed to human use. But we are now reaching the ceiling of productive land expansion, in terms of sheer area, while the continued productivity of arable land is threatened by salinity, acidity and toxic metal levels that have now degraded soils across one third of the earth's surface, some of them irreversibly.



Figure *Page*14.3.3 Global Forest Map. Since the middle of the twentieth century, the global logging industry, and hence large-scale deforestation, has shifted from the North Atlantic countries to the forests of tropical regions such as Indonesia and the Amazon Basin in Latin America. This tropical "green belt" is now rapidly diminishing, with devastating consequences for local ecosystems, water resources, and global climate. Source: NASA

Wetlands Drainage and Damming

Meanwhile, the worlds' vital wetlands, until recently viewed as useless swamps, have been ruthlessly drained—15% worldwide, but over half in Europe and North America. The draining of wetlands has gone hand in hand with large-scale hydro-engineering projects that proliferated through the last century, such that now some two-thirds of the world's fresh water passes through dam systems, while rivers have been blocked, channeled, and re-routed to provide energy, irrigation for farming, and water for urban development. The long-term impacts of these projects were rarely considered in the planning stages, and collectively they constitute a wholesale re-engineering of the planet's hydrological system in ways that will be difficult to adapt to the population growth demands and changing climatic conditions of the 21stcentury. As for the world's oceans, these increasingly show signs of acidification due to carbon emissions, threatening the aquatic food chain and fish stocks for human consumption, while on the surface, the oceans now serve as a global conveyor belt for colossal amounts of non-degradable plastic debris.

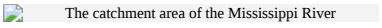


Figure *Page*14.3.4 Mississippi Watershed Map. The catchment area of the Mississippi River covers almost 40% of the U.S. continental landmass, collecting freshwater from 32 states. Included in the runoff that feeds the river system are large quantities of agricultural fertilizer and other chemicals that eventually drain into the Gulf of Mexico, creating an ever-growing "dead zone." Source: Environmental Protection Agency

Air Pollution

In many parts of the world, pollution of the air by industrial particles is now less a problem than it was a century ago, when newspapers lamented the "black snow" over Chicago. This is due to concerted efforts by a clean air caucus of international scope that arose in the 1940s and gained significant political influence with the emergence of the environmental movement in the 1970s. The impact of the post-70s environmental movement on the quality of air and water, mostly in the West, but also developing countries such as India, is the most hopeful precedent we have that the sustainability issues facing the world in the new century might yet be overcome, given political will and organization equal to the task.

Climate Change

Air pollution is still a major problem in the megacities of the developing world, however, while a global change in air chemistry—an increase of 40% in the carbon load of the atmosphere since industrialization—is ushering in an era of accelerated climate change. This era will be characterized by increased droughts and floods, higher sea levels, and extreme weather events, unevenly and unpredictably distributed across the globe, with the highest initial impact in regions that, in economic and infrastructural terms, can least support climate disruption (for example, sub-Saharan Africa). The environmental historian J. R. McNeil estimates that between 25 and 40 million people died from air pollution in the 20th century. The death toll arising from climate change in the 21st century is difficult to predict, but given the scale of the disruption to weather systems on which especially marginal states depend, it is likely to be on a much larger scale.

Summary

From the Portuguese sea merchants of the 16th century in quest of silver and spices from Asia, to the multinational oil companies of today seeking to drill in ever more remote and fragile undersea regions, the dominant view driving global economic growth over

the last half millennium has been instrumentalist, that is, of the world's ecosystems as alternately a source of raw materials (foods, energy, minerals) and a dump for the wastes produced by the industrialization and consumption of those materials. The instrumentalist economic belief system of the modern era, and particularly the Industrial Age, is based on models of perennial growth, and measures the value of ecosystems according to their production of resources maximized for efficiency and hence profit. In this prevailing system, the cost of resource extraction to the ecosystem itself is traditionally not factored into the product and shareholder values of the industry. These costs are, in economic terms, externalized.

A future economics of sustainability, by contrast, would prioritize the management of ecosystems for resilience rather than pure capital efficiency, and would incorporate the cost of ecosystem management into the pricing of goods. In the view of many sustainability theorists, dismantling the system of "unnatural" subsidization of consumer goods that has developed over the last century in particular is the key to a sustainable future. Only a reformed economic system of natural pricing, whereby environmental costs are reflected in the price of products in the global supermarket, will alter consumer behavior at the scale necessary to ensure economic and environmental objectives are in stable alignment, rather than in constant conflict. As always in the sustainability paradigm, there are tradeoffs. A future economy built on the principle of resilience would be very different from that prevalent in the economic world system of the last 500 years in that its managers would accept reduced productivity and efficiency in exchange for the long-term vitality of the resource systems on which it depends.

Review Questions

1. What are the major technological and economic developments since 1500 that have placed an increased strain on thge planet's ecosystem services? What is the role of carbon-based energy systems in that history?
2. What is the so-called Great Acceleration of the 20th century? What were its principal social features and environmental impacts?
3. What is the Green Revolution? What were its successes, and what problems has it created?

Glossary

Biodiversity and Extinction

Thriving ecosystems are characterized by diverse plant and animal populations; there is, therefore, a strong correlation between current ecosystem decline globally, and the rate of extinction of species, which is in the order of a thousand times that of background rates. This has prompted scientists to label the current period the Sixth Mass Extinction in the long history of the biosphere, and the first since the end of the dinosaurs.

Externalization

The process by which costs inherent to the production of goods—particularly environmental costs—are not included in the actual price paid.

Instrumentalist

An attitude to environmental resources characteristic of the last 500-year period of global human economic development, whereby ecosystem provisions—water, minerals, oil and gas, etc.—are perceived only in terms of their use value to human beings, rather than as integral elements of a wider natural system.

Nonlinear

Changes in a system are nonlinear when they exhibit sudden changes in rate of increase or decline. The population of a particular tropical frog species, for example, may suddenly crash as a result of warming temperatures, rather than show gradual decline.

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Page 14.4: Case Study- Agriculture and the Global Bee Colony Collapse

Two thousand years ago, at the height of the Roman Empire, the poet Virgil wrote lovingly about the practice of beekeeping, of cultivating the “aerial honey and ambrosial dews” he called “gifts of heaven” (*Georgics* IV: 1-2). Bees represent a gift to humanity even greater that Virgil knew. In addition to satisfying the human appetite for honey, the Italian honeybee, *Apis melliflora*, is the world’s most active pollinator, responsible for over 80 of the world’s most common nongrain crops, including apples, berries, almonds, macadamias, pumpkins, melons, canola, avocadoes, and also coffee beans, broccoli and lettuce. Even the production chain of the enormous meat and cotton industries relies at crucial points on the ministrations of the humble honeybee. We depend on pollinated fruits, nuts and seeds for a third of our caloric intake, and for vital vitamins, minerals and antioxidants in our diet. In total, around 80% of the foods we eat are to some degree the products of bee pollination, representing one third of total agricultural output.

Given the $1 trillion value of pollinated produce, any threat to the health of honey bees represents a serious threat to the human food chain—a classic sustainability issue. With the industrialization of the global agricultural system over the last 50 years—including crop monoculture and mass fertilization—bees have indeed faced a series of threats to their ancient role, the most recent of which, so-called Colony Collapse Disorder, is the most serious yet.



Figure *Page*14.4.1 Busy Bee Hive. A forager honeybee comes in for landing at a healthy hive, her legs dusted with pollen. Colony Collapse Disorder has devastated tens of thousands of such hives. Source: Ken Thomas

In his poetic primer on beekeeping, Virgil includes a moving description of a bee colony suffering mysterious decline:

“Observe the symptoms when they fall away” “ And languish with insensible decay.” “ They change their hue; with haggard eyes they stare . . .” “ The sick, for air, before the portal gasp,” “ Their feeble legs within each other clasp,” “ Or idle in their empty hives remain,” “ Benumbed with cold, and listless of their gain. (368-78”

Beekeepers worldwide faced an even worse predicament in late 2006: the mysterious disappearance of entire hives of bees. Over the winter, honeybees enter a form of survival hibernation. Their populations suffer inevitable losses, but these are replenished by the Queen’s renewed laying of eggs once winter thaws. In the spring of 2007, however, hundreds of thousands of colonies in the United States did not survive the winter. A full 30% of all honeybee colonies died. Each spring since has witnessed even worse declines. Similar losses afflicted Europe and Asia. Worldwide, millions of colonies and billions of bees have perished since 2006 on account of the new bee plague.

Because the global commercial value of bee pollination is so enormous, well-funded research into colony collapse began immediately. A number of theories, some credible, some not, were quickly advanced. Several studies pointed to new or enhanced viral strains, while others suggested the toxic effect of industrial fertilization. Still others claimed that mobile phone towers were interfering with the bees’ navigations systems. Because the honeybee is a charismatic creature and features so prominently in our cultural lore—we admire their industriousness, fear their stings, call our loved ones “honey,” and talk much of Queen Bees—the story of colony collapse was quickly taken up by the media. A flurry of news stories announced CCD as an epic “disaster” and profound “mystery,” which was true in simple terms, but which cast bee decline as a new and sudden calamity for which some single culprit must be responsible.

The truth, as it is now unfolding, is more complex, and shows the importance of viewing the interactions between human and natural ecologies in systemic terms. In strictly pathogenic terms, CCD is caused by the combination of a virus (called *Iridoviridae* or IIV) and a microsporidian fungus called *Nosema*. The specific interaction between the pathogens, and why they cause bees in their millions to vacate their hives, is not understood. What is becoming clear, however, is the increasing burden being placed on bees by the human agricultural system, a burden that has rendered bees increasingly vulnerable to epidemic infection. Humans have been keeping bees for eight thousand years, and European bees were at the vanguard of the successful crop colonization of the Americas. But the numbers of bees in the United States had already declined by a third since 1950 before the arrival of CCD, owing to various viral and mite infestations, and the large scale changes in bee habitat and lifestyle.

Before the industrialization of farming, bees came from neighboring wildlands to pollinate the diverse range of crops available to them on small plots. But the conversion, for economic reasons, of arable land into enormous monocrop properties in the last sixty years, and hence the diminishment of proximate wildflower habitats, has necessitated a different system, whereby bees are trucked

around the country to service one crop at a time, be it peppers in Florida, blueberries in Maine, or almonds in California. At the height of the recent almond boom, the California crop required almost the entire bee population of the United States to be fully pollinated. Wholesale suburbanization is also to blame for the destruction of the bees' natural wildflower habitats. Be it a thousand acre cornfield or a suburban street of well-tended green lawns, to a bees' eyes, our modern landscape, engineered to human needs, is mostly a desert.

Studies that have not identified specific culprits for CCD have nevertheless shown the extent of the long-term decline in bee health wrought by their conscription to industrial agriculture. For instance, researchers found no fewer than 170 different pesticides in samples of American honeybees, while other studies found that even bees not suffering CCD habitually carry multiple viral strains in their systems. The combined toxic and viral load for the average honeybee is enormous. In the words of Florida's state apiarist, "I'm surprised honey bees are alive at all." (Jacobsen, 2008, p. 137) A further study showed a decline in the immune systems of bees owing to lack of diverse nutrition. Pollinating only almonds for weeks on end, then travelling on a flatbed truck for hundreds of miles in order to service another single crop, is not the lifestyle bees have adapted to over the near 80 million years of their existence. As Virgil warned, "First, for thy bees a quiet station find." The lives of modern bees have been anything but quiet, and the enormous changes in their habitat and lifestyle have reduced their species' resilience.

The most important lesson of recent research into CCD is not the identification of IIV and *Nosema* as the specific contributors, but the larger picture it has provided of a system under multiple long-term stresses. Complex systems, such as bee pollination and colony maintenance, are not characterized by linear development, but rather by sudden, nonlinear changes of state called tipping points. CCD is an example of a potential tipping point in a natural system on which humans depend, in which sudden deterioration overtakes a population beyond its ability to rebound. Everything seems fine, until it isn't. One day we have almonds, berries, melon, and coffee on our breakfast menu. The next day there's a critical shortage, and we can't afford them.

In sustainability terms, bee colony collapse is a classic "human dimensions" issue. CCD will not be "solved" simply by the development of a new anti-viral drug or pesticide targeting the specific pathogens responsible. Part of what has caused CCD is the immunosuppressive effects of generations of pesticides developed to counter previous threats to bee populations, be they microbes or mites. Our chemical intervention in the lifecycle of bees has, in evolutionary terms, "selected" for a more vulnerable bee. That is, bees' current lack of resilience is a systemic problem in our historical relationship to bees, which dates back thousands of years, but which has altered dramatically in the last fifty years in ways that now threaten collapse. And this is to say nothing of the impact of bee colony collapse on other pollination-dependent animals and birds, which would indeed be catastrophic in biodiversity terms.

That we have adapted to bees, and they to us, is a deep cultural and historical truth, not simply a sudden "disaster" requiring the scientific solution of a "mystery." In the light of sustainability systems analysis, the bee crisis appears entirely predictable and the problem clear cut. The difficulty arises in crafting strategies for how another complex system on a massive scale, namely global agriculture, can be reformed in order to prevent *its* collapse as one flow-on effect of the global crisis of the vital honey bee. The incentive for such reform could not be more powerful. The prospect of a future human diet without fruits, nuts and coffee is bleak enough for citizens of the developed world and potentially fatal for millions of others in the long term.

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Review Questions

1. What is the long history of the human relationship to bees, and what radical changes in that relationship have occurred over the last fifty years to bring it to the point of collapse?
2. What are the implications of bee colony collapse for the global food system?

Glossary

Tipping Point

The critical moment of nonlinear change whereby a system changes suddenly from one state to another.

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Page 14.5: Sustainability Ethics

Developing an Ethics of Sustainability

The 1987 United Nations Brundtland definition of sustainability embodies an *intergenerational contract*: to provide for our present needs, while not compromising the ability of future generations to meet their needs. It's a modest enough proposal on the face of it, but it challenges our current expectations of the intergenerational contract: we expect each new generation to be better off than their parents. Decades of technological advancement and economic growth have created a mindset not satisfied with "mere" sustainability. We might call it turbo-materialism or a cornucopian worldview: namely that the earth's bounty, adapted to our use by human ingenuity, guarantees a perpetual growth in goods and services. At the root of the cornucopian worldview lies a brand of technological triumphalism, an unshakeable confidence in technological innovation to solve all social and environmental problems, be it world hunger, climate change, or declining oil reserves. In sustainability discourse, there is a wide spectrum of opinion from the extremes of cornucopian optimism on one side and to the doom-and-gloom scenarios that suggest it is already too late to avert a new Dark Age of resource scarcity and chronic conflict on the other.



Figure *Page*14.5.1 California, the Cornucopia of the World Cover of an 1885 promotional book prepared by the California Immigration Commission. Source: The California State Library

For every generation entering a Dark Age, there were parents who enjoyed a better life, but who somehow failed to pass along their prosperity. No one wants to fail their children in this way. To this extent, biology dictates multigenerational thinking and ethics. Though it might not always be obvious, we are all already the beneficiaries of multi-generational planning. The world-leading American higher education system, for example, depends upon an intergenerational structure and logic—a financial and human investment in the future committed to by multiple generations of Americans going back to the 19th century. But conversely, in terms of vulnerability, just as higher education in the United States is neither necessarily permanent nor universal, but a social institution built on an unwritten contract between generations, so the lifestyle benefits of advanced society as we know it will not simply perpetuate themselves without strenuous efforts to place them on a sustainable footing.

Our current problem lies in the fact that multigenerational thinking is so little rewarded. Our economic and political systems as they have evolved in the Industrial Age reward a mono-generational mindset driven by short-term profits and election cycles. In the West, for example, there is no significant political philosophy, regulatory system, or body of law that enshrines the idea that we act under obligation to future generations, despite widely held views that we naturally must. One challenge of sustainability is to channel our natural biological interest in the future into a new ethics and politics based on multigenerational principles. Many indigenous communities in the world, marginalized or destroyed by colonialism and industrialization, have long recognized the importance of sustainability in principles of governance, and provide inspiring models. The Great Law of the Iroquois Confederacy, for example, states that all decisions made by its elders should be considered in light of their impact seven generations into the future.

To embrace an ethics of sustainability is to accept that our rapid industrialization has placed us in the role of planetary managers, responsible for the health, or ruinous decline, of many of the globe's vital ecosystems. This ethics requires we activate, in the popular sense, both sides of our brain. That is, we must toggle between a rational consideration of our environmental footprint and practical issues surrounding the reinvention of our systems of resource management, and a more humble, intuitive sense of our dependence and embeddedness within the web of life. Both reason and emotion come into play. Without emotion, there can be no motivation for change. Likewise, without an intellectual foundation for sustainability, our desire for change will be unfocused and ineffective. We are capable of adapting to a complex world and reversing broad-based ecosystem decline. But to do so will require technical knowledge wedded to an ethical imagination. We need to extend to the natural world the same moral sense we intuitively apply to the social world and our relations with other people.

Sustainability ethics thus does not need to be invented from whole cloth. It represents, in some sense, a natural extension of the ethical principles dominant in the progressive political movements of the 20th century, which emphasized the rights of historically disenfranchised communities, such as women, African-Americans, and the global poor. Just as we have been pressed to speak for dispossessed peoples who lack a political voice, so we must learn the language of the nonhuman animal and organic world, of "nature," and to speak for it. Not simply for charity's sake, or out of selfless concern, but for our own sake as resource-dependent beings.

Remote Responsibilities

What distinguishes an ethics of sustainability from general ethical principles is its emphasis on remote responsibilities, that is, our moral obligation to consider the impact of our actions on people and places far removed from us. This distance may be measured in both space and time. First, in spatial terms, we, as consumers in the developed world, are embedded in a global web of commerce, with an ethical responsibility toward those who extract and manufacture the goods we buy, whether it be a polo shirt from Indonesia, or rare metals in our computer extracted from mines in Africa. The economic and media dimensions of our consumer society do not emphasize these connections; in fact, it is in the interests of "consumer confidence" (a major economic index) to downplay the disparities in living standards between the markets of the developed world and the manufacturing countries of the global south (Africa, Asia, Latin America), which serve as the factories of the world.

Second, as for sustainability ethics considered in temporal terms, the moral imagination required to understand our remote responsibilities poses an even greater challenge. As we have seen, the landmark United Nations Brundtland Report establishes an ethical contract between the living and those yet to be born. For an industrial civilization founded on the no-limits extraction of natural resources and on maximizing economic growth in the short term, this is actually a profoundly difficult challenge to meet. More than that, the practical ethical dilemmas it poses to us in the present are complex. How, for instance, are we to balance the objectives of economic development in poorer nations—the need to lift the world's "bottom billion" out of poverty—with the responsibility to conserve resources for future generations, while at the same time making the difficult transition from industrialized fossil fuels to a low-carbon global economy?

The issue of fairness with regard to individual nations' carbon emissions reduction mandates is a specific example of how ethical issues can complicate, or even derail, negotiated treaties on environmental sustainability, even when the parties agree on the end goal. In the view of the developing countries of the global south, many of them once subject to colonial regimes of the north, the advanced industrialized countries, such as the United States and Europe, should bear a heavier burden in tackling climate change through self-imposed restraints on carbon consumption. They after all have been, over the last 200 years, the principal beneficiaries of carbon-driven modernization, and thus the source of the bulk of damaging emissions. For them now to require developing nations to curb their own carbon-based modernization for the benefit of the global community reeks of neo-colonial hypocrisy. Developing nations such as India thus speak of common but differentiated responsibilities as the ethical framework from which to justly share the burden of transition to a low-carbon global economy.

From the point of view of the rich, industrialized nations, by contrast, whatever the appearance of historical injustice in a carbon treaty, all nations will suffer significant, even ruinous contractions of growth if an aggressive mitigation agreement among all parties is not reached. Some commentators in the West have further argued that the sheer scale and complexity of the climate change problem means it cannot effectively be addressed through a conventional rights-based and environmental justice approach. To this degree at least, the sustainability issue distinguishes itself as different in degree and kind from the landmark social progressive movements of the 20th century, such as women's emancipation, civil rights, and multiculturalism, to which it has often been compared.

Disputes over the complex set of tradeoffs between environmental conservation and economic development have dominated environmental policy and treaty discussions at the international level for the last half century, and continue to stymie progress on issues such as climate change, deforestation, and biofuels. These problems demonstrate that at the core of sustainability ethics lies a classic tragedy of the commons, namely, the intractable problem of persuading individuals, or individual nations, to take specific responsibility for resources that have few or no national boundaries (the atmosphere, the oceans), or which the global economy allows to be extracted from faraway countries, the environmental costs of which are thus "externalized" (food, fossil fuels, etc). How the international community settles the problem of shared accountability for a rapidly depleting global commons, and balances the competing objectives of economic development and environmental sustainability, will to a large extent determine the degree of decline of the planet's natural capital this century. One tragic prospect looms: If there is no international commitment, however patchwork, to protect the global resource commons, then the gains in economic prosperity, poverty alleviation and public health in the developing world so hard won by international agencies over the second half of the 20th century, will quickly be lost.

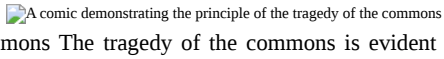


Figure $Page14.5.2$ Tragedy of Commons The tragedy of the commons is evident in many areas of our lives, particularly in the environment. The over-fishing of our oceans that causes some marine life to be in danger of extinction is a good example. Source: Food and Agriculture Organization of the United Nations

Precautionary Principle

The precautionary principle is likewise central to sustainability ethics. The margins of uncertainty are large across many fields of the biophysical sciences. Simply put, there is a great deal we do not know about the specific impacts of human activities on the natural resources of land, air, and water. In general, however, though we might not have known where the specific thresholds of resilience lie in a given system—say in the sardine population of California's coastal waters—the vulnerability of ecosystems to human resource extraction is a constant lesson of environmental history. A prosperous and vital economic engine, the Californian sardine fishery collapsed suddenly in the 1940s due to overfishing. The precautionary principle underlying sustainability dictates that in the face of high risk or insufficient data, the priority should lie with ecosystem preservation rather than on industrial development and market growth.



Figure $Page14.5.3$ Great Fish Market by Jan Brueghel Though we might not have known where the specific thresholds of resilience lie in a given system—say in the sardine population of California's coastal waters—the vulnerability of ecosystems to human resource extraction is a constant lesson of environmental history. Source: Public Domain

Sustainability, in instances such as these, is not a sexy concept. It's a hard sell. It is a philosophy of limits in a world governed by dreams of infinite growth and possibility. Sustainability dictates that we are constrained by earth's resources as to the society and lifestyle we can have. On the other hand, sustainability is a wonderful, inspiring concept, a quintessentially human idea. The experience of our own limits need not be negative. In fact, what more primitive and real encounter between ourselves and the world than to feel our essential dependence on the biospheric elements that surround us, that embeddedness with the air, the light, the warmth or chill on our skins, and the stuff of earth we eat or buy to propel ourselves over immense distances at speed unimaginable to the vast armies of humanity who came before us.

Sustainability studies is driven by an ethics of the future. The word itself, sustainability, points to proofs that can only be projected forward in time. To be sustainable is, by definition, to be attentive to what is to come. So sustainability requires imagination, but sustainability studies is also a profoundly historical mode, committed toreconstruction of the long, nonlinear evolutions of our dominant extractivist and instrumentalist views of the natural world, and of the "mind-forg'd manacles" of usage and ideology that continue to limit our ecological understanding and inhibit mainstream acceptance of the sustainability imperative.

Sustainability studies thus assumes the complex character of its subject, multiscalar in time and space, and dynamically agile and adaptive in its modes. Sustainability teaches that the environment is not a sideshow, or a scenic backdrop to our lives. A few more or less species. A beautiful mountain range here or there. Our relation to our natural resources is the key to our survival. That's why it's called "sustainability." It's the grounds of possibility for everything else. Unsustainability, conversely, means human possibilities and quality of life increasingly taken away from us and the generations to come.

Review Questions

1. What does it mean to say that global environmental problems such as climate change and ocean acidification represent a "tragedy of the commons?" How are global solutions to be tied to local transitions toward a sustainable society?
2. How does sustainability imply an "ethics of the future?" And in what ways does sustainability ethics both borrow and diverge from the principles that drove the major progressive social movements of the 20th century?

Glossary

Common but Differentiated Responsibilities

An ethical framework, promoted particularly by developing nations, that recognizes mitigation of global warming as a shared responsibility, but at the same time argues that the wealthy, industrialized countries of the West that have been the historical beneficiaries of carbon-based development should accept a greater burden for both reducing global carbon emissions, and providing developing nations with the technology and economic means to modernize in sustainable ways.

Cornucopian

The view that economic growth and technological innovation will continue to improve the conditions of humanity as they have done for the past 500 years, and that no environmental constraints are important or permanent.

Precautionary Principle

The proposition that decision-making should be driven by a concern for the avoidance of bad outcomes. In environmental terms, this means coordinating economic development and the profit motive with the need to maintain resilient ecosystems.

Remote Responsibilities

An ethical extension of systems literacy and the principle of connectivity: we are linked to peoples and places remote from us through the web of global industrial production and commerce, and thus have responsibility toward them.

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Index

A

acid rain
Page 13.3: Acid Rain

age structure
Page 5.3: The Human Population

Aquatic Biomes
Page 4.2: Aquatic Biomes

B

bioenergetics
Page 3.2: Energy

biological agents
Page 8.1: The Impacts of Environmental Conditions

Bioremediation
Page 8.4: Bioremediation

C

carrying capacity
Page 5.2: Population Growth and Regulation

community
Page 5.4: Community Ecology

Community Ecology
Page 5.4: Community Ecology

competitive exclusion principle
Page 5.4: Community Ecology

Crop rotations
Page 11.5: Sustainable Agriculture

D

DDT
Page 8.1: The Impacts of Environmental Conditions

demography
Page 5.1: Population Demographics and Dynamics

E

ecological footprint
Page 1.3: Environment and Sustainability

Environmental Toxicology
Page 8.3: Environmental Toxicology

exponential growth
Page 5.2: Population Growth and Regulation

F

Food Security
Page 10.1: Food Security

frontier ethic
Page 1.4: Environmental Ethics

G

genetic engineering
Page 10.2: Biotechnology and Genetic Engineering

H

herbivory
Page 5.4: Community Ecology

Human Population
Page 5.3: The Human Population

I

Integrated Pest Management
Page 11.5: Sustainable Agriculture

Intercropping
Page 11.5: Sustainable Agriculture

L

logistic growth
Page 5.2: Population Growth and Regulation

M

Mimicry
Page 5.4: Community Ecology

minimal tillage
Page 11.5: Sustainable Agriculture

O

Organic Farming
Page 11.5: Sustainable Agriculture

Ozone Depletion
Page 13.2: Ozone Depletion

P

paleosols
Page 11.1: Soil Profiles and Processes

Persistent organic pollutants (POPs)
Page 11.4: Pests and Pesticides

pest
Page 11.4: Pests and Pesticides

Pesticides
Page 11.4: Pests and Pesticides

Population Growth
Page 5.2: Population Growth and Regulation

precautionary principle
Page 1.3: Environment and Sustainability

predator
Page 5.4: Community Ecology

S

Soil processes
Page 11.1: Soil Profiles and Processes

Soil Profiles
Page 11.1: Soil Profiles and Processes

Sustainable Agriculture
Page 11.5: Sustainable Agriculture

symbiosis
Page 5.4: Community Ecology

T

Terrestrial Biomes
Page 4.1: Terrestrial Biomes

Glossary

accuracy: | The degree to which a measurement or observation reflects the actual value. Compare with precision.

acid rain: | The wet deposition only of acidifying substances from the atmosphere. See also acidifying deposition.

acid shock: | An event of relatively acidic surface water that can occur in the springtime when the snowpack melts quickly but the ground is still frozen.

acid sulphate soil: | Acidic soil conditions caused when certain wetlands are drained and sulphide compounds become oxidized.

acid-mine drainage: | Acidic water and soil conditions that develop when sulphide minerals become exposed to the atmosphere, allowing them to be oxidized by Thiobacillus bacteria.

acid-neutralizing capacity: | The quantitative ability of water to neutralize inputs of acid without becoming acidified. See also buffering capacity.

acidification: | An increasing concentration of hydrogen ions (H^+) in soil or water.

acidifying deposition: | Both the wet and dry deposition of acidifying substances from the atmosphere.

acute toxicity: | Toxicity associated with short-term exposures to chemicals in concentrations high enough to cause biochemical or anatomical damages, even death. Compare with chronic toxicity.

aerobic: | Refers to an environment in which oxygen (O_2) is readily available. Compare with anaerobic.

aesthetic pollution: | Substantially a matter of cultural values, this commonly involves images that are displeasing to many (but not necessarily all) people.

afforestation: | Establishment of a forest where one did not recently occur, as when trees are planted on agricultural land.

age-class structure: | The proportions of individuals in various age classes of a population.

agricultural site capability: | See site capability.

agroecosystem: | An ecosystem used for the production of food.

agroforestry: | The cultivation of trees in plantations, typically using relatively intensive management practices.

algal bloom: | An event of high phytoplankton biomass.

ammonification: | Oxidation of the organically bound nitrogen of dead biomass into ammonium (NH_4+).

anaerobic: | Refers to an environment in which oxygen (O_2) is not readily available. Compare with aerobic.

angiosperm: | Flowering plants that have their ovules enclosed within a specialized membrane and their seeds within a seedcoat. Compare with gymnosperm.

anthropocentric world view: | This considers humans as being more worthy than other species and uniquely disconnected from nature. The importance and worth of everything is considered in terms of the implications for human welfare. Compare with biocentric world view and ecocentric world view.

anthropogenic: | Occurring as a result of a human influence.

applied ecology: | The application of ecological principles to deal with economic and environmental problems.

aquaculture: | The cultivation of fish and other aquatic species.

aquifer: | Groundwater resources in some defined area.

artificial selection: | The deliberate breeding of species to enhance traits that are viewed as desirable by humans.

artificial wetland: | An engineered wetland, usually constructed to treat sewage or other organic wastes.

aspect: | The direction in which a slope faces.

assimilation efficiency: | In an animal, the percentage of the energy content of ingested food that is absorbed across the gut wall. In plants, the percentage of solar visible light that is fixed by photosynthesis. The term may also be used to refer to the percentage assimilation of ingested inorganic nutrients (such as nitrate or phosphate) by plants or animals, or of drugs by animals.

atmosphere: | The gaseous envelope surrounding the Earth, held in place by gravity.

atmospheric inversion (temperature inversion): | A relatively stable atmospheric condition in which cool air is trapped beneath a layer of warmer air.

atmospheric water: | Water occurring in the atmosphere, in vapour, liquid, or solid forms.

atom bomb: | An explosive device that is based on the uncontrolled "splitting" of certain fissile isotopes of uranium and/or plutonium.

autecology: | The field within ecology that deals with the study of individuals and species. Compare with synecology.

autotroph: | An organism that synthesizes its biochemical constituents using simple inorganic compounds and an external source of energy to drive the process. See also primary producer, photoautotroph, and chemoautotroph.

available concentration: | The concentration of metals in an aqueous extract of soil, sediment, or rocks, simulating the amount available for organisms to take up from the environment. Compare with total concentration.

baby boom: | A period of high fecundity during 1945–1965 that occurred because of social optimism after the Second World War.

background concentration: | A presence or concentration of a substance that is not significantly influenced by either anthropogenic emissions or unusual natural exposures.

binomial: | Two latinized words that are used to name a species.

bio-resource: | A renewable resource that is biological in character.

bioaccumulation (bioconcentration): | The occurrence of chemicals in much higher concentrations in organisms than in the ambient environment. Compare with food-web magnification.

biocentric world view: | This considers all species (and individuals) as having equal intrinsic value. Humans are not considered more important or worthy than any other species. Compare with anthropocentric world view and ecocentric world view.

bioconcentration: | See bioaccumulation.

biodegradation: | The breakdown of organic molecules into simpler compounds through the metabolic actions of microorganisms.

biodiversity crisis: | The present era of high rates of extinction and endangerment of biodiversity.

biodiversity: | The richness of biological variation, including genetic variability as well as species and community richness.

biogeochemical prospecting: | Prospecting for metal ores using observations of high metal concentrations in plants, soil, or surface rocks.

biological control: | Pest-control methods that depend on biological interactions, such as diseases, predators, or herbivores.

biological oxygen demand (BOD): | The capacity of organic matter and other substances in water to consume oxygen during decomposition.

biomagnification: | See food-web magnification.

biomass energy: | The chemical potential energy of plant biomass, which can be combusted to provide thermal energy.

biome: | A geographically extensive ecosystem, occurring throughout the world wherever environmental conditions are suitable.

biophilia: | An innate love of people for nature

biosphere: | All life on Earth, plus their ecosystems and environments.

birth control: | Methods used to control fertility and childbirth.

BOD: | See biological oxygen demand.

bog: | An infertile, acidic, unproductive wetland that develops in cool but wet climates. Compare with fen.

boreal coniferous forest: | A northern forest dominated by coniferous trees, usually species of fir, larch, pine, or spruce. See also boreal forest.

boreal forest (taiga): | An extensive biome occurring in environments with cold winters, short but warm growing seasons, and moist soils, and usually dominated by coniferous trees.

broad-spectrum pesticide: | A pesticide that is toxic to other organisms as well as the pest.

broadcast spray: | A pesticide treatment over a large area.

browse: | Broad-leaved shrubs that are eaten by herbivores such as hares and deer.

bryophyte: | Simple plants that do not have vascular tissues nor a cuticle on their foliage.

buffering capacity: | The ability of a solution to resist changes in pH as acid or base is added.

by-catch: | Inadvertent harvesting of a non-target species.

calorie: | A standard unit of energy, defined as the amount of energy needed to raise the temperature of one gram of pure water from 15°C to 16°C. Compare with joule.

carbon credits: | Actions that help reduce the atmospheric concentration of CO_2, such as fossil-fuel conservation and planting trees.

carbon credits: | See carbon credits.

carnivore (secondary consumer): | An animal that hunts and eats other animals.

carrying capacity: | The abundance of a species that can be sustained without the habitat becoming degraded.

chaparral: | A shrub-dominated ecosystem that occurs in south- temperate environments with winter rains and summer drought.

chemical weapons: | Weapons that cause deaths or injuries through exposure to toxic chemicals.

chemoautotroph: | Microorganisms that harness some of the potential energy of certain inorganic chemicals (e.g., sulphides) to drive their fixation of energy through chemosynthesis. Compare with photoautotroph.

chemosynthesis: | Autotrophic productivity that utilizes energy released during the oxidation of certain inorganic chemicals (such as sulphides) to drive biosynthesis. Compare with photosynthesis.

chromosome: | Subcellular unit composed of DNA and containing the genetic information of eukaryotic organisms.

chronic toxicity: | Toxicity associated with exposure to small or moderate concentrations of chemicals, sometimes over a long period of time. The damages may be biochemical or anatomical, and may include the development of a lethal disease, such as cancer. Compare with acute toxicity.

clear-cutting: | The harvesting of all economically useful trees from an area at the same time.

climate change: | Long-term changes in air, soil, or water temperature; precipitation regimes; wind speed; or other climate-related factors.

climate: | The prevailing, long-term, meteorological conditions of a place or region, including temperature, precipitation, wind speed, and other factors. Compare with weather.

coal washing: | See fuel desulphurization.

coal: | An organic-rich, solid fossil fuel mined from sedimentary geological formations.

coarse woody debris: | Logs lying on the forest floor.

coevolution: | This occurs when species interact in ways that affect their reciprocal survival, and so are subject to a regime of natural selection that reinforces their mutual evolutionary change.

collective properties: | This term is used in reference to the summation of the parts of a system. See also emergent properties.

commensalism: | A symbiosis in which one of the species benefits from the interaction, while the other is not affected in either a positive or negative way.

commercial energy production: | The use of solid, liquid, and gaseous fuels, plus all electricity. Does not include the use of traditional fuels. See also total energy production and traditional fuels.

commercial extinction: | Depletion of a natural resource to below the abundance at which it can be profitably harvested.

common-property resource: | A resource shared by all of society, not owned by any particular person or interest.

community-replacing disturbance: | A disturbance that results in the catastrophic destruction of an original community, and its replacement by another one. Compare with microdisturbance.

community: | In ecology, this refers to populations of various species that are co-occurring at the same time and place.

compaction: | A decrease in the pore space of soil (or increased bulk density) caused by the passage of heavy machinery.

compartment: | A reservoir of mass in a nutrient or material cycle.

competition: | A biological interaction occurring when the demand for an ecological resource exceeds its limited supply, causing organisms to interfere with each other.

competitor: | A species that is dominant in a habitat in which disturbance is rare and environmental stresses are unimportant, so competition is the major influence on evolution and community organization.

compost: | Partially decomposed, well-humified organic material

composting: | The processing of discarded organic material by encouraging decomposition processes under warm, moist, oxygen-rich conditions. The product, known as compost, is a useful fertilizer and soil conditioner.

conservation: | Wise use of natural resources. Conservation of nonrenewable resources involves recycling and other means of efficient use. Conservation of renewable resources includes these means, in addition to ensuring that harvesting does not exceed the rate of regeneration of the stock.

contamination: | The presence of potentially damaging chemicals in the environment, but at concentrations less than those required to cause toxicity or other ecological damages. Compare with pollution.

control (control treatment): | An experimental treatment that was not manipulated, and is intended for comparison with manipulated treatments.

conventional economics: | Economics as it is commonly practised, which includes not accounting for costs associated with ecological damages and resource depletion. Compare with ecological economics.

conventional munitions: | Explosive devices that are based on chemical reactions, such as cordite and dynamite.

convergence (evolutionary conversion): | This occurs when unrelated species with similar niches and living in comparable environments are subjected to parallel regimes of natural selection, resulting in their evolution to be similar in morphology, physiology, and behaviour.

conversion: | See ecological conversion.

core: | Earth's massive interior, made up of hot molten metals.

Coriolis effect: | An influence of Earth's west-to-east rotation, which makes winds in the Northern Hemisphere deflect to the right and those in the Southern Hemisphere to the left.

creationist: | A person who rejects the theory of evolution in favour of a literal interpretation of Genesis, the first book of the Old Testament of the Bible. See also scientific creationist.

critical load: | A threshold for pollutant inputs, below which it is thought ecological damages will not be caused.

crude oil washing (COW) method: | A method of washing a tanker's oil-storage components with a spray of crude oil before the next cargo is loaded. This eliminates the use of wash-water and avoids an important cause of marine oil pollution.

crude oil: | See petroleum.

crust: | The outermost layer of Earth's sphere, overlying the lithosphere and composed mostly of crystalline rocks.

cultural eutrophication: | Eutrophication caused by anthropogenic nutrient inputs, usually through sewage dumping or fertilizer runoff. See also eutrophication.

cultural evolution: | Adaptive evolutionary change in human society, characterized by increasing sophistication in the methods, tools, and social organizations used to exploit the environment and other species. Compare with evolution.

cultural identity: | A complex of self-identified characteristics and values that a group of people considers important in defining their distinct quality.

culture: | The shared beliefs, values, and knowledge of a defined group of people.

cumulative environmental impacts: | Environmental impacts that result from a proposed undertaking, in addition to those caused by any past, existing, and imminent developments and activities.

decay: | The decomposition or oxidation of dead biomass, mostly through the actions of microorganisms.

decomposer: | See detritivore.

deductive logic: | Logic in which initial assumptions are made and conclusions are then drawn from those assumptions. Compare with inductive logic.

deep drainage: | Soil water that has drained to below the lower limits of plant roots.

deforestation: | A permanent conversion of forest into some other kind of ecosystem, such as agriculture or urbanized land use.

demographic transition: | A change in human population parameters from a condition of high birth and death rates to one of low birth and death rates.

denitrification: | The microbial reduction of nitrate (NO_3–) into gaseous N_2O or N_2.

desert: | A temperate or tropical biome characterized by prolonged drought, usually receiving less than 25 cm of precipitation per year.

desertification: | The increasing aridity of drylands; an environmental change that can make agriculture difficult or impossible.

detritivore: | A heterotroph that feeds on dead organic matter.

developed countries: | Countries with a relatively well-organized economic infrastructure and a high average per-capita income. See also high-income countries and compare with less-developed countries.

development (economic development): | An economic term that implies improving efficiency in the use of materials and energy in an economy, and progress toward a sustainable economic system. Compare with economic growth.

discipline: | A specific area of study, such as mathematics or music.

disturbance: | An episode of destruction of some part of a community or ecosystem.

DNA: | The biochemical deoxyribonucleic acid, the main constituent of the chromosomes of eukaryotic organisms.

domestication: | The genetic, anatomic, and physiological modification of crops and other species from their wild, progenitor species, through the selective breeding of preferred races (or cultivars).

dose-response relationship: | The quantitative relationship between different doses of a chemical and a biological or ecological response.

doubling time: | The time it takes for something to increase by a factor of two (as in population growth).

drift: | Movement of applied pesticide off the intended site of deposition through atmospheric or aquatic transport.

dry deposition: | Atmospheric inputs of chemicals occurring in intervals between rainfall or snowfall. Compare with wet deposition.

dumping: | The long-term disposal of disused material, for example, by placing solid waste into a sanitary landfill, or by discarding liquid waste into a waterbody.

earthquake: | A trembling or movement of the earth, caused by a sudden release of geological stresses at some place within the crust.

ecocentric world view: | This incorporates the biocentric world view but also stresses the importance of interdependent ecological functions, such as productivity and nutrient cycling. In addition, the connections among species within ecosystems are considered to be invaluable. Compare with anthropocentric world view and biocentric world view.

ecofeminism: | A philosophical and political movement that applies feminist ideas to environmental concerns.

ecological conversion: | A long-term change in the character of the ecosystem at some place, as when a natural forest is converted into an agricultural land use.

ecological economics: | A type of economics that involves a full accounting of costs associated with ecological damages and resource depletion. Compare with conventional economics.

ecological footprint: | The area of ecoscape (i.e., landscape and seascape) required to supply a human population with the necessary food, materials, energy, waste disposal, and other crucial goods and services.

ecological integrity (ecosystem health): | A notion related to environmental quality, but focusing on changes in natural populations and ecosystems, rather than effects on humans and their economy. See also environmental quality.

ecological justice: | A worldview in which all species (i.e., not just humans) have a right to equitable access to the necessities of life and happiness. See also social justice.

ecological pyramid: | A model of the trophic structure of an ecosystem, organized with plant productivity on the bottom, that of herbivores above, and carnivores above the herbivores.

ecological service: | An ecological function that is useful to humans and to ecosystem stability and integrity, such as nutrient cycling, productivity, and control of erosion.

ecological stress: | See stressors.

ecological sustainability: | See ecologically sustainable development.

ecological values: | Broader utilitarian values that are based on the needs of humans, but also on those of other species and natural ecosystems.

ecologically sustainable development: | This considers the human need for resources within an ecological context, and includes the need to sustain all species and all components of Earth's life-support system. Compare with sustainable development.

ecologically sustainable economic system: | An economic system that operates without a net consumption of natural resources, and without endangering biodiversity or other ecological values. Ultimately, ecologically sustainable economic systems are supported by the wise use of renewable resources.

ecologically sustainable economy: | An economy in which ecological goods and services are utilized in ways that do not compromise their future availability and do not endanger the survival of species or natural ecosystems.

ecology: | The study of the relationships between organisms and their environment.

economic development: | See development.

economic growth: | A term that refers to an economy that is increasing in size over time, usually due to increases in both population and per capita resource use. Compare with development.

ecoregion: | See ecozone.

ecoscape: | A general term for landscapes or seascapes.

ecosystem approach: | A holistic interpretation of the natural world that considers the web-like interconnections among the many components of ecosystems.

ecosystem health: | See ecological integrity.

ecosystem: | A general term used to describe one or more communities that are interacting with their environment as a defined unit. Ecosystems range from small units occurring in microhabitats, to larger units such as landscapes and seascapes, and even the biosphere.

ecotone: | A zone of transition between two distinct habitats.

ecotoxicology: | Study of the directly poisonous effects of chemicals in ecosystems, plus indirect effects such as changes in habitat or food abundance caused by toxic exposures. Compare with toxicology and environmental toxicology.

ecotype: | A population specifically adapted to coping with locally stressful conditions, such as soil with high metal concentrations.

ecozone: | The largest biophysical zones in the national ecological classification of Canada.

electromagnetic energy: | Energy associated with photons, comprising an electromagnetic spectrum divided into components, including ultraviolet, visible, and infrared.

emergent property: | A used in reference to synergetic properties that are greater than the summation of the parts of a system. See also collective properties.

emissions trading: | A system in which a company whose that has not exceeded its cap on emissions of a regulated substance, such as SO_2, can sell its "surplus" to another that is likely to exceed its cap.

endangered: | In Canada, this specifically refers to indigenous species threatened with imminent extinction or extirpation over all or a significant portion of their Canadian range.

endemic: | An ecological term used to describe species with a local geographic distribution.

energy budget: | An analysis of the rates of input and output of energy to a system, plus transformations of energy among its states, including changes in stored quantities.

energy production: | See total energy production.

energy: | The capacity of a body or system to accomplish work, and existing as electromagnetic, kinetic, and potential energies.

entropy: | A physical attribute related to the degree of randomness of the distributions of matter and energy.

environment (the): | (1) Refers to influences on organisms and ecosystems, including both non-living (abiotic) and biological factors; (2) An indeterminate word for issues associated with the causes and consequences of environmental damage, or with the larger environmental crisis.

environmental citizenship: | Actions taken by individuals and families to lessen their impacts on the environment.

environmental degradation: | Refers to pollution, disturbance, resource depletion, lost biodiversity, and other kinds of environmental damage; usually refers to damage occurring accidentally or intentionally as a result of human activities (see also anthropogenic), but can also be caused by natural disasters or stressors.

environmental discrimination (environmental prejudice): | Discrimination against any defined group that results in them suffering a disproportionate amount of degradation or pollution of their living or work environment. See also environmental racism.

environmental ecology: | See applied ecology

environmental education: | A way of fostering environmental literacy by incorporating environmental issues in educational curricula, both in specialized classes as well as across the curriculum, and also including the out-of-school public.

environmental ethics: | These deal with the responsibilities of the present human generation to ensure continued access to adequate resources and livelihoods for future generations of people and other species.

environmental impact assessment (EIA): | A process used to identify and evaluate the potential consequences of proposed actions or policies for environmental quality. See also socioeconomic impact assessment.

environmental indicators: | Relatively simple measurements that are sensitive to changes in the intensity of stressors, and are considered to represent complex aspects of environmental quality.

environmental literacy: | Refers to an objective understanding, by individuals and society-at-large, of the causes and consequences of environmental problems.

environmental monitoring: | Repeated measurements of indicators related to the inorganic environment or to ecosystem structure and function.

environmental mutagen: | A mutagenic influence that is encountered in the environment. See also mutagen.

environmental non-governmental organizations (ENGOs): | Charities and other not-for-profit organizations that are working in the environmental field. See also non-governmental organizations.

environmental quality: | A notion related to the amounts of toxic chemicals and other stressors in the environment, to the frequency and intensity of disturbances, and to their effects on humans, other species, ecosystems, and economies.

environmental racism: | Discrimination against a group of people defined by racial attributes, which results in them suffering a disproportionate amount of degradation or pollution of their living or work environment. See also environmental discrimination.

environmental reporting: | Communication of information about changes in environmental quality to interest groups and the general public.

environmental risk assessment: | A quantitative evaluation of the risks associated with an environmental hazard.

environmental risk: | A hazard or probability of suffering damage or misfortune because of exposure to some environmental circumstance.

environmental science: | An interdisciplinary branch of science that investigates questions related to the human population, resources, and damages caused by pollution and disturbance.

environmental scientist: | A scientist who is specialized in some aspect of environmental science.

environmental security: | The protection of people and the public interest from environmental risks, particularly those associated with anthropogenic activities and accidents, but may also include natural dangers.

environmental stressor: | See stressor.

environmental studies: | An extremely interdisciplinary approach that examines the scientific, social, and cultural aspects of environmental issues.

environmental teratogen: | A teratogenic influence that is encountered in the environment. See also teratogen.

environmental toxicology: | The study of environmental factors influencing exposures of organisms to potentially toxic levels of chemicals. Compare with toxicology and ecotoxicology.

environmental values: | Perceptions of the worth of environmental components, divided into two broad classes: utilitarian and intrinsic.

environmentalist: | Anyone with a significant involvement with environmental issues, usually in an advocacy sense.

erosion: | The physical removal of rocks and soil through the combined actions of flowing water, wind, ice, and gravity.

estuary: | A coastal, semi-enclosed ecosystem that is open to the sea and has habitats transitional between marine and freshwater conditions.

ethics: | The perception of right and wrong. The proper behaviour of people toward each other and toward other species and nature.

eukaryote: | Organisms in which the cells have an organized, membrane-bound nucleus containing the genetic material. Compare with prokaryote.

eutrophic: | Pertains to waters that are highly productive because they contain a rich supply of nutrients. Compare with oligotrophic and mesotrophic.

eutrophication: | Increased primary productivity of an aquatic ecosystem, resulting from nutrient inputs.

evaporation: | The change of state of water from a liquid or solid to a gas.

evapotranspiration: | Evaporation of water from a landscape. See also transpiration.

evolution: | Genetically based changes in populations of organisms, occurring over successive generations.

evolutionary ecology: | The interpretation of ecological knowledge in terms of evolution, natural selection, and related themes.

experiment: | A controlled test or investigation designed to provide evidence for, or preferably against, a hypothesis about the natural or physical world.

exposure assessment: | An investigation of the means by which organisms may encounter a potentially toxic level of a chemical or other environmental stressor.

exposure: | In ecotoxicology, this refers to the interaction of organisms with an environmental stressor at a particular place and time.

extant: | A species that still exists. Compare with extinct.

externality: | A cost or benefit that is received, even though the affected party did not choose to incur it.

extinct (extinction): | A condition in which a species or other taxon no longer occurs anywhere on Earth.

extinction crisis: | See biodiversity crisis.

extinction vortex: | An accelerating spiral of endangerment and extinction caused by worsening environmental conditions.

extirpated (extirpation): | A condition in which a species or other taxon no longer occurs in some place or region, but still survives elsewhere.

fact: | An event or thing known to have happened, to exist, or to be true. See also hypothesis.

fen: | A wetland that develops in cool and wet climates, but is less acidic and more productive than a bog because it has a better nutrient supply. Compare with bog.

first law of thermodynamics: | A physical principle stating that energy can undergo transformations among its various states, but it is never created or destroyed; thus, the energy content of the universe remains constant. See also second law of thermodynamics.

First Nations: | The Aboriginal people(s) originally living in some place. This term is often used in reference to the original inhabitants of the Americas, prior to the colonization of those regions by Europeans, and their modern descendants.

fission bomb: | See atom bomb.

fission reaction: | Nuclear reaction involving the splitting of heavier, radioactive atoms into lighter ones, with the release of large quantities of energy.

fitness: | The proportional contribution of an individual to the progeny of its population.

flow-through system: | A system with an input and an output of energy or mass, plus temporary storage of any difference.

flue-gas desulphurization: | A process to remove SO_2 from the waste (flue) gases of a power plant or smelter, before they are discharged into the atmsophere.

flux: | A movement of mass or energy between compartments of a material or energy cycle.

food chain: | A hierarchical model of feeding relationships among species in an ecosystem.

food web: | A complex model of feeding relationships, describing the connections among all food chains within an ecosystem.

food-web magnification (food-web accumulation | The tendency for top predators in a food web to have the highest residues of certain chemicals, especially organochlorines. Compare with bioaccumulation.

forest floor: | Litter and other organic debris lying on top of the mineral soil of a forest.

forestry: | The harvesting of trees and management of post-harvest succession to foster the regeneration of another forest.

fossil fuel: | Organic-rich geological materials, such as coal, petroleum, and natural gas.

frontier world view: | This asserts that humans have a right to exploit nature by consuming natural resources in boundless quantities. See also sustainability world view and spaceship world view.

fuel desulphurization: | A process that removes much of the sulphur content of coal before it is used as a fuel in a power plant.

fuel switching: | The replacement of a high-sulphur fuel, such as coal, by an energy source that does not emit sulphur gases, such as hydroelectricity or nuclear power.

full-cost accounting system: | An accounting system that considers all costs, including those of environmental damage.

fungicide: | A pesticide used to protect crop plants and animals from fungi that cause diseases or other damages.

fusion bomb: | See hydrogen bomb.

fusion reaction: | Nuclear reaction involving the combining of light nuclei, such as those of hydrogen, to make heavier ones, with the release of large quantities of energy. Fusion reactions occur under conditions of intense temperature and pressure, such as within stars and in hydrogen bombs.

Gaia hypothesis: | A notion that envisions Earth's species and ecosystems as a "superorganism" that attempts to optimize environmental conditions toward enhancing its own health and survival.

gaseous wastes: | The gaseous products of combustion or industrial reactions.

gene: | A region of a chromosome, containing a length of DNA that behaves as a particulate unit in inheritance and determines the development of a specific trait.

genocide: | The mass killing of an identifiable group as an attempted extermination.

genotype: | The genetic complement of an individual organism. See also phenotype.

geography: | The study of the features of the surface of the Earth, including topography, landforms, soil, climate, and vegetation, as well as the intersections of these with the economic interests of humans.

geothermal energy: | Heat in Earth's crust, which can sometimes be used to provide energy for heating or generation of electricity.

glaciation: | An extensive environmental change associated with an extended period of global climatic cooling and characterized by advancing ice sheets.

glacier: | A persistent sheet of ice, occurring in the Arctic and Antarctic and at high altitude on mountains.

greater protected area: | A protected area plus its immediately surrounding area, co-managed to sustain populations of indigenous species and natural communities.

green manure: | Living plant biomass that is grown and then incorporated into the soil by tillage.

green revolution: | Intensive agricultural systems involving the cultivation of improved crop varieties in monoculture, and increased use of mechanization, fertilizers, and pesticides.

greenhouse effect: | The physical process by which infrared-absorbing gases (such as CO_2) in Earth's atmosphere help to keep the planet warm.

greenhouses gases (GHGs): | Atmospheric gases that efficiently absorb infrared radiation and then dissipate some of the thermal energy gain by re-radiation. Synonym: ** radiatively active gases.

gross domestic product (GDP): | The total annual value of all goods and services produced domestically within a country. GDP is equivalent to gross national product minus net investment income from foreign countries. See also gross national product (GNP).

gross national product (GNP): | The total annual value of all goods and services produced domestically by a country, including net foreign investment income. See also gross domestic product (GDP).

gross primary production (GPP): | The fixation of energy by primary producers within an ecosystem. See also respiration, net primary production, and autotroph.

groundwater drainage: | The drainage of water to storage places in the ground, occurring under the influence of gravity.

groundwater: | Water stored underground in soil and rocks.

growth: | Refers to an economy or economic sector that is increasing in size over time. Compare with development.

gymnosperm: | Vascular plants such as conifers, which have naked ovules not enclosed within a specialized membrane, and seeds without a seedcoat. Compare with angiosperm.

habitat: | The place or "home" where a plant or animal lives, including the specific environmental factors required for its survival.

harvesting effort: | The amount of harvesting, which is a function of both the means (such as the kinds of fishing gear) and the intensity (the number of boats and the amount of time each spends fishing).

harvesting mortality: | Anthropogenic mortality, especially that due to the harvesting of a bio-resource. Compare with natural mortality.

hazardous waste: | Wastes that are flammable, explosive, toxic, or otherwise dangerous. See also toxic waste.

herbicide: | A pesticide used to kill weeds. See also weed.

herbivore (or primary consumer): | An animal that feeds on plants.

heterotroph: | An organism that utilizes living or dead biomass as food.

hidden injury: | A reduction in plant productivity caused by exposure to pollutants, but not accompanied by symptoms of acute tissue damages.

high-income countries: | Countries with a relatively high average per-capita income. See also developed countries and compare with low-income countries.

hormonally active substance: | A hormone or another chemical that has an effect on the regulation of biochemistry. See also hormone.

hormone: | A biochemical produced in an endocrine gland (and transported by the blood) that functions to regulate a metabolic process. Some chemicals in food may mimic the function of hormones produced naturally in the body.

humidity: | The actual concentration of water in the atmosphere, usually measured in mg/m^3. Compare with relative humidity.

humus: | Amorphous, partially decomposed organic matter. An important and persistent type of soil organic matter, it is very important in soil tilth and fertility.

hydrocarbons: | Molecules composed of hydrogen and carbon only.

hydroelectric energy: | Electricity generated using the kinetic energy.

hydrogen bomb: | A nuclear weapon that is based on the fusion of nuclei of deuterium and tritium, two isotopes of hydrogen.

hydrologic (water) cycle: | The movement between, and storage of water in, various compartments of the hydrosphere. See also hydrosphere.

hydrosphere: | The parts of the planet that contain water, including the oceans, atmosphere, on land, in surface waterbodies, underground, and in organisms.

hyperaccumulator: | A species that bioaccumulates metals or other chemicals to extremely high concentrations in their tissues. See also bioaccumulation.

hypereutrophic: | Extremely eutrophic waters; usually considered to be a degraded ecological condition. See also eutrophic.

hypersensitivity: | An extreme sensitivity to exposure to some environmental factor, resulting in a biological response such as asthma, disease, or even death. It may be expressed at the species or individual level, and it involves responses at relatively low intensities of exposure that the great majority of species or individuals could tolerate.

hypothesis: | A proposed explanation for the occurrence or causes of natural phenomena. Scientists formulate hypotheses as statements, and test them through experiments and other forms of research. See also fact.

igneous rock: | Rock such as basalt and granite, formed by cooling of molten magma.

impoundment: | An area of formerly terrestrial landscape that is flooded behind a dam.

incineration: | The combustion of mixed solid wastes to reduce the amount of organic material present.

indicator: | See environmental indicator.

indigenous culture: | A human culture existing in a place or region prior to its invasion, or other significant influence, by a foreign culture.

individual organism: | A genetically and physically discrete living entity.

inductive logic: | Logic in which conclusions are objectively developed from the accumulating evidence of experience and the results of experiments. See also deductive logic.

inequitable: | Not equitable or fair.

inherent value: | See intrinsic value

inhumane: | Reflecting a lack of pity or compassion; most commonly refers to the cruel treatment by humans of other animals.

insecticide: | A pesticide used to kill insects that are considered pests. See also pesticide and pest.

instrumental value: | See utilitarian value

integrated forest management: | Forest management plans that accommodate the need to harvest timber from landscapes, while also sustaining other values, such as hunted wildlife, outdoor recreation, and biodiversity.

integrated pest management (IPM): | The use of a variety of complementary tactics toward pest control, with the aim of having fewer environmental and health risks.

interdisciplinary: | Encompassing a wide diversity of kinds of knowledge.

intrinsic population change: | Population change due only to the balance of birth and death rates.

intrinsic value: | Value that exists regardless of any direct or indirect value in terms of the needs or welfare of humans.

invasive alien: | Refers to non-native species that survive in wild habitats and possibly aggressively out-compete native species or cause other kinds of ecological damage.

inversion: | See atmospheric inversion.

invertebrate: | Any animal that lacks an internal skeleton, and in particular a backbone.

joule: | A standard unit of energy, defined as the energy needed to accelerate 1 kg of mass at 1 m/s2 for a distance of 1 metre. Compare with calorie.

K-selected: | Refers to organisms that produce relatively small numbers of large offspring. A great deal of parental investment is made in each progeny, which helps to ensure their establishment and survival. Compare with r-selected.

keystone species: | A dominant species in a community, usually a predator, with an influence on structure and function that is highly disproportionate to its biomass.

kinetic energy: | Energy associated with motion, including mechanical and thermal types.

knowledge: | Information and understanding about the natural world.

landscape ecology: | Study of the spatial characteristics and temporal dynamics of communities over large areas of land (landscapes) or water (seascapes).

landscape: | The spatial integration of ecological communities over a large terrestrial area.

laws of thermodynamics: | Physical principles that govern all transformations of energy. See also first law of thermodynamics and second law of thermodynamics.

leaching: | The movement of dissolved substances through the soil with percolating rainwater.

legacy munitions: | See unexploded ordinance.

lentic ecosystem: | A freshwater ecosystem characterized by nonflowing water, such as a pond or lake. Compare with lotic ecosystem.

less-developed countries: | Countries with a relatively well-organized economic infrastructure and a high average per-capita income. See also high-income countries and compare with developed countries.

life form: | A grouping of organisms on the basis of their common morphological and physiological characteristics, regardless of their evolutionary relatedness.

life index (production life): | The known reserves of a resource divided by its current rate of production.

liming: | Treatment of a waterbody or soil to reduce acidity, usually by adding calcium carbonate or calcium hydroxide.

limiting factor: | An environmental factor that is the primary restriction on the productivity of autotrophs in an ecosystem. See also Principle of Limiting Factors.

liquid waste: | Variable urban wastes that include sewage and discarded industrial and household fluids.

lithification: | A geological process in which materials are aggregated, densified, and cemented into new sedimentary rocks.

lithosphere: | An approximately 80-km thick region of rigid, relatively light rocks that surround Earth's plastic mantle.

load-on-top (LOT) method: | A process used in ocean-going petroleum tankers to separate and contain most oily residues before ballast waters are discharged to the marine environment.

long-range transport of air pollutants: | See LRTAP.

lotic ecosystem: | A freshwater ecosystem characterized by flowing water, such as a stream or river. Compare with lentic ecosystem.

low-income counties: | Countries with a relatively small average per-capita income. See also less-developed countries and compare with high-income countries.

LRTAP: | The long-range transport of atmospheric pollutants.

macroclimate: | Climatic conditions affecting an extensive area. Compare with microclimate.

macroevolution: | The evolution of species or higher taxonomic groups, such as genera, families, or classes. Compare with microevolution.

management system: | A variety of management practices used in a coordinated manner.

manipulative experiment: | An experiment involving controlled alterations of factors hypothesized to influence phenomena, conducted to investigate whether predicted responses will occur, thereby uncovering causal relationships. See also experiment and natural experiment.

mantle: | A less-dense region that encloses Earth's core, and composed of minerals in a hot, plastic state known as magma.

marsh: | A productive wetland, typically dominated by species of monocotyledonous angiosperm plants that grow as tall as several metres above the water surface.

mass extinction: | An event of synchronous extinction of many species, occurring over a relatively short period of time. May be caused by natural or anthropogenic forces.

maximum sustainable yield (MSY): | The largest amount of harvesting that can occur without degrading the productivity of the stock.

mechanization: | The use of specialized machinery to perform work, instead of the labour of people or animals.

megacity: | A large city, sometimes defined as having a population greater than 8 million people.

mesosphere: | The layer of the atmosphere extending beyond the stratosphere to about 75 km above the surface of the Earth. See also stratosphere.

mesotrophic: | Pertains to aquatic ecosystems of moderate productivity, intermediate to eutrophic and oligotrophic waters. Compare with eutrophic and oligotrophic.

metal: | Any relatively heavy element that in its pure state shares electrons among atoms, and has useful properties such as malleability, high conductivity of electricity and heat, and tensile strength.

metamorphic rock: | Rock formed from igneous or sedimentary rocks that have changed in structure under the influences of geological heat and pressure.

meteorite: | An extraterrestrial rock-like object; very rarely, one may intersect with Earth's orbit and impact the planet.

microclimate: | Climatic conditions on a local scale. Compare with macroclimate.

microdisturbance: | Local disruptions that affect small areas within an otherwise intact community. Compare with community-replacing disturbance.

microevolution: | Relatively subtle evolutionary changes occurring within a population or species, sometimes within only a few generations, and at most leading to the evolution of races, varieties, or subspecies. Compare with macroevolution.

middle-income countries: | Countries with a rapidly increasing average per-capita income. See also high-income and low-income countries and compare with developed countries and less-developed countries.

militarism: | A belief of people or governments in the need to maintain a strong military capability to defend or promote national interests.

mitigation: | An action that repairs or offsets environmental damages to some degree.

monoculture: | The cultivation of only one species while attempting to exclude others from the agroecosystem.

montane forest: | A conifer-dominated forest occurring below the alpine zone on mountains.

MSY: | See maximum sustainable yield.

mutagen: | A chemical or physical agent (e.g., ultraviolet radiation) that is capable of inducing genetic mutations.

mutualism (mutualistic symbiosis): | A symbiosis in which both partners benefit.

natural capital: | See natural resource

natural experiment: | An experiment conducted by observing variations of phenomena in nature, and then developing explanations for these through analysis of potential causal mechanisms. See also experiment and manipulative experiment.

natural gas: | A gaseous, hydrocarbon-rich mixture mined from certain geological formations.

natural mortality: | Mortality due to natural causes. Compare with harvesting mortality.

natural population change: | A change in population that is due only to the difference in birth and death rates, and not to immigration or emigration.

natural resource: | A source of material or energy that is extracted (harvested) from the environment.

natural selection: | A mechanism of evolution, favouring individuals that, for genetically based reasons, are better adapted to coping with environmental opportunities and constraints. These more fit individuals have an improved probability of leaving descendants, ultimately leading to genetically based changes in populations, or evolution.

natural: | Refers to a non-anthropogenic context, i.e., one that is not influenced by humans and is self-organizing and dominated by native species; see also nature.

nature: | Refers to the entire system of physical and biological existence and organization, uninfluenced by humans; see also natural.

net ecosystem productivity: | The amount of ecosystem-level productivity that remains after respiration is subtracted from gross productivity.

net primary production (NPP): | Primary production that remains as biomass after primary producers have accounted for their respiratory needs. See also respiration and gross primary production.

niche: | The role of a species within its community.

NIMBY: | An acronym for "not in my backyard".

nitrification: | The bacterial oxidation of ammonium (NH_4^+) to nitrate (NO_3^-).

nitrogen fixation: | The oxidation of nitrogen gas (N_2) to ammonia (NH_3) or nitric oxide (NO).

noise pollution: | When the level of ambient sound becomes distracting to the normal activities of people. At a higher intensity it can cause hearing impairment.

non-governmental organizations (NGOs): | Charities and other not- for-profit organizations. See also environmental non-governmental organizations.

non-renewable resource (non-renewable natural resource): | A resource present on Earth in finite quantities, so as it is used, its future stocks are diminished. Examples are metals and fossil fuels. Compare with renewable resources.

non-target damage: | Damage caused by a pesticide to non-target organisms. See also broad-spectrum pesticide and non-target organism.

non-target organism: | Organisms that are not pests, but which may be affected by a pesticide treatment. See also broad-spectrum pesticide and non-target damage.

not in my backyard: | See NIMBY.

nuclear fuel: | Unstable isotopes of uranium (^{235}U) and plutonium (^{239}Pu) that decay through fission, releasing large amounts of energy that can be used to generate electricity.

nuclear winter: | A period of prolonged climate cooling that might be caused by a nuclear war.

null hypothesis: | A hypothesis that seeks to disprove a hypothesis.

nutrient budget: | A quantitative estimate of the rates of nutrient input and output for an ecosystem, as well as the quantities present and transferred within the system.

nutrient capital: | The amount of nutrients present in a site in soil, living vegetation, and dead organic matter.

nutrient cycling: | Transfers and chemical transformations of nutrients in ecosystems, including recycling through decomposition.

nutrient: | Any chemical required for the proper metabolism of organisms.

ocean: | The largest hydrological compartment, accounting for about 97% of all water on Earth.

old-growth forest: | A late-successional forest characterized by the presence of old trees, an uneven-aged population structure, and a complex physical structure.

oligotrophic: | Pertains to aquatic ecosystems that are highly unproductive because of a sparse supply of nutrients. Compare with eutrophic and mesotrophic.

omnivore: | An animal that feeds on both plant and animal materials.

organic agriculture: | Systems by which crops are grown using natural methods of maintaining soil fertility, and pest-control methods that do not involve synthetic pesticides.

orographic precipitation: | Precipitation associated with hilly or mountainous terrain that forces moisture-laden air to rise in altitude and become cooler, causing water vapour to condense into droplets that precipitate as rain or snow.

outer space: | Regions beyond the atmosphere of Earth.

over-harvesting (over-exploitation): | Unsustainable harvesting of a potentially renewable resource, leading to a decline of its stocks.

oxidizing smog: | An event of air pollution rich in ozone, peroxy acetyl nitrate, and other oxidant gases.

paradigm: | A pattern or model; a collection of assumptions, concepts, practices, and values that constitutes a way of viewing reality, especially for an intellectual community that shares them.

parameter: | One or more constants that determine the form of a mathematical equation. In the linear equation $Y = aX + b$, a and b are parameters, and Y and X are variables. See also variable.

parasitism: | A biological relationship involving one species obtaining nourishment from a host, usually without causing its death.

peace-keeping: | An action that occurs after a hot conflict has stopped through a cease-fire agreement, but the conditions for a lasting peace are not yet in place so various means must be used to keep the antagonists apart. Compare with peace-making.

peace-making: | The enforced resolution of an active or potential conflict, often by establishing a balanced power relationship among the parties while also imposing a process to achieve a negotiated settlement. Compare with peace-keeping.

peace: | The absence of war.

persistence: | The nature of chemicals, especially pesticides, to remain in the environment before eventually being degraded by microorganisms or physical agents such as sunlight and heat.

pest: | Any organism judged to be significantly interfering with some human purpose.

pesticide treadmill: | The inherent reliance of modern agriculture and public-health programs on pesticides, often in increasing quantities, to deal with pest problems.

pesticide: | A substance used to poison pests. See also pest, fungicide, herbicide, and insecticide.

petroleum (crude oil): | A fluid, hydrocarbon-rich mixture mined from certain geological formations.

phenotype: | The expressed characteristics of an individual organism, due to genetic and environmental influences on the expression of its specific genetic information. See also genotype.

phenotypic plasticity: | The variable expression of genetic information of an individual, depending on environmental influences during development.

photoautotroph: | Plants and algae that use sunlight to drive their fixation of energy through photosynthesis. See also chemoautotroph and photosynthesis.

photochemical air pollutants: | Ozone, peroxy acetyl nitrate, and other strongly oxidizing gases that form in the atmosphere through complex reactions involving sunlight, hydrocarbons, oxides of nitrogen, and other chemicals.

photosynthesis: | Autotrophic productivity that utilizes visible electromagnetic energy (such as sunlight) to drive biosynthesis.

phytoplankton: | Microscopic, photosynthetic bacteria and algae that live suspended in the water of lakes and oceans.

plantation: | In forestry, these are tree-farms managed for high productivity of wood fibre.

poaching: | The illegal harvesting of wild life (plants or animals).

point source: | A location where large quantities of pollutants are emitted into the environment, such as a smokestack or sewer outfall.

political ecology: | This integrates the concerns of ecology and political economy to consider the dynamic tensions between natural and anthropogenic change, and also the consideration of damage from both natural and anthropogenic perspectives; the latter includes the broad range of concerns from individual people to all of society.

pollution: | The exposure of organisms to chemicals or energy in quantities that exceed their tolerance, causing toxicity or other ecological damages. Compare with contamination.

population: | In ecology, this refers to individuals of the same species that occur together in time and space.

potential energy: | The stored ability to perform work, capable of being transformed into electromagnetic or kinetic energies. Potential energy is associated with gravity, chemicals, compressed gases, electrical potential, magnetism, and the nuclear structure of matter.

potentially renewable natural resource: | An alternate phrase for renewable natural resource, highlighting the fact that these can be overexploited, and thereby treated as if they were nonrenewable resources. See also renewable resource.

ppb (part per billion): | A unit of concentration, equivalent to 1 microgram per kilogram (µg/kg), or in aqueous solution, 1 µg per litre (µg/L).

ppm (part per million): | A unit of concentration, equivalent to 1 milligram per kilogram (mg/kg), or in aqueous solution, 1 mg per litre (mg/L).

prairie: | Grassland ecosystems occurring in temperate regions.

precautionary principle: | An approach to environmental management, adopted by many countries at the 1992 Earth Summit, which essentially states that scientific uncertainty is not a sufficient reason to postpone control measures when there is a threat of harm to human health or the environment.

precipitation: | Deposition of water from the atmosphere as liquid rain, or as solid snow or hail.

precision: | The degree of repeatability of a measurement or observation. Compare with accuracy.

prevailing wind: | Wind that blows in a dominant direction.

primary consumer: | A herbivore, or a heterotrophic organism that feeds on plants or algae.

primary pollutants: | Chemicals that are emitted into the environment. Compare with secondary pollutants.

primary producer: | An autotrophic organism. Autotrophs are the biological foundation of ecological productivity. See also primary production.

primary production: | Productivity by autotrophic organisms, such as plants or algae. Often measured as biomass accumulated over a unit of time, or sometimes by the amount of carbon fixed.

primary sewage treatment: | The initial stage of sewage treatment, usually involving the filtering of larger particles from the sewage wastes, settling of suspended solids, and sometimes chlorination to kill pathogens.

Principle of Limiting Factors: | A theory stating that ecological productivity (and some other functions) is controlled by whichever environmental factor is present in least supply relative to the demand.

production life: | See life index.

production: | An ecological term related to the total yield of biomass from some area or volume of habitat.

productivity: | An ecological term for production standardized per unit area and time.

prokaryote: | Microorganisms without an organized nucleus containing their genetic material. Compare with eukaryote.

protected area (reserve): | Parks, ecological reserves, and other tracts set aside from intense development to conserve their natural ecological values. See also greater protected area.

r-selected: | Refers to organisms that produce relatively large numbers of small offspring. Little parental investment is made in each offspring, but having large numbers of progeny helps ensure that some will establish and survive. Compare with K-selected.

radiatively active gases (RAGs): | Atmospheric gases that efficiently absorb infrared radiation and then dissipate some of the thermal energy gain by reradiation.

rapidly developing countries: | Countries with a quickly growing economic infrastructure and a rapidly increasing average per-capita income. See also high-income and low-income countries and compare with developed countries and less-developed countries.

reclamation: | Actions undertaken to establish a self-maintaining ecosystem on degraded land, as when a disused industrial site is converted into a permanent cover of vegetation, such as a pasture. Compare with restoration and remediation.

recycling: | The processing of discarded materials into useful products.

relative humidity: | The atmospheric concentration of water, expressed as a percentage of the saturation value for that temperature.

remediation: | Specific actions undertaken to deal with particular problems of environmental quality, such as the liming of acidic lakes and rivers to decrease their ecological damage. Compare with restoration and reclamation.

renewable resource (renewable natural resource): | These can regenerate after harvesting, and potentially can be exploited forever. Examples are fresh water, trees, agricultural plants and livestock, and hunted animals. Compare with nonrenewable resources.

replacement fertility rate: | The fertility rate that results in the numbers of progeny replacing their parents, with no change in size of the equilibrium population.

replication: | The biochemical process occurring prior to cellular division, by which information encoded in DNA is copied to produce additional DNA with the same information.

reserve: | (1) Known quantities of resources that can be economically recovered from the environment. (2) An alternative word for a protected area. See protected area.

residence time: | (1) The time required for the disappearance of an initial amount; (2) The length of time that a stressor or other environmental influence remains active.

residue: | Lingering concentrations of pesticides and certain other chemicals in organisms and the environment.

resilience: | The ability of a system to recover from disturbance.

resistance: | The ability of a population or community to avoid displacement from some stage of ecological development as a result of disturbance or an intensification of environmental stress. Changes occur after thresholds of resistance to environmental stressors are exceeded.

resource recovery facility: | See waste-to-energy facility.

respiration: | Physiological processes needed to maintain organisms alive and healthy.

response: | In ecotoxicology, this refers to biological or ecological changes caused by exposure to an environmental stressor.

restoration ecology: | Activities undertaken by ecologists to repair ecological damage, such as establishing vegetation on degraded habitat, increasing the populations of endangered species, and decreasing the area of threatened ecosystems.

restoration: | Establishment of a self-maintaining facsimile of a natural ecosystem on degraded land, as when abandoned farmland is converted back to a native prairie or forest. Compare with reclamation and remediation.

reuse: | Finding another use for discarded materials, usually with relatively little modification.

risk assessment: | See environmental risk assessment.

risk: | See environmental risks.

RNA: | The biochemical ribonucleic acid, which is important in translation of the genetic information of DNA into the synthesis of proteins. RNA also stores the genetic information of some viruses.

ruderal: | Short-lived but highly fecund plants characteristic of frequently disturbed environments with abundant resources.

run-of-the-river: | A hydroelectric development that directly harnesses the flow of a river to drive turbines, without creating a substantial impoundment for water storage.

salinization: | The buildup of soluble salts in the soil surface, an important agricultural problem in drier regions.

sanitary landfill: | A facility where municipal solid waste is dumped, compacted by heavy machines, and covered with a layer of clean dirt at the end of the day. Some have systems to contain and collect liquid effluent, known as leachate.

science: | The systematic and quantitative study of the character and behaviour of the physical and biological world.

scientific creationist: | A creationist who attempts to explain some of the discrepancies between his or her beliefs (which are based on a literal interpretation of Genesis) and scientific understanding of the origin and evolution of life. See also creationist.

scientific method: | This begins with the identification of a question involving the structure or function of the natural world, usually using inductive logic. The question is interpreted in terms of a theory, and hypotheses are formulated and tested by experiments and observations of nature.

scrubbing: | See flue-gas desulphurization.

seascape: | A spatial integration of ecological communities over a large marine area.

second law of thermodynamics: | A physical principle stating that transformations of energy can occur spontaneously only under conditions in which there is an increase in the entropy (or randomness) of the universe. See also first law of thermodynamics and entropy.

secondary consumer: | A carnivore that feeds on primary consumers (or herbivores).

secondary pollutants: | Pollutants that are not emitted, but form in the environment by chemical reactions involving emitted chemicals. Compare with primary pollutants.

secondary sewage treatment: | Treatment applied to the effluent of primary sewage treatment, usually involving the use of a biological technology to aerobically decompose organic wastes in an engineered environment. The resulting sludge can be used as a soil conditioner, incinerated, or dumped into a landfill. See also primary sewage treatment.

sedimentary rock: | Rock formed from precipitated minerals such as calcite, or from lithified particles eroded from other rocks such as sandstone, shale, and conglomerates.

sedimentation: | A process by which mass eroded from elsewhere settles to the bottom of rivers, lakes, or an ocean.

seismic sea wave: | See tsunami.

selection harvesting: | Harvesting of only some trees from a stand, leaving others behind and the forest substantially intact.

sewage treatment: | The use of physical filters, chemical treatment, and/or biological treatment to reduce pathogens, organic matter, and nutrients in waste waters containing sewage.

shifting cultivation: | An agricultural system in which trees are felled, the woody debris burned, and the land used to grow mixed crops for several years.

significant figures: | The number of digits used when reporting data from analyses or calculations.

silvicultural management: | The application of practices that increase tree productivity in a managed forest, such as planting seedlings, thinning trees, or applying herbicides to reduce the abundance of weeds.

silviculture: | The branch of forestry concerned with the care and tending of trees.

site capability (site quality): | The potential of land to sustain the productivity of agricultural crops.

slash-and-burn: | An agricultural system that results in a permanent conversion of a forest into crop production, involving cutting and burning the forest followed by continuous use of the land for crops.

slope: | The angle of inclination of land, measured in degrees (0° implies a horizontal surface, while 90° is vertical).

SLOSS: | An acronym, for single large or several small, in reference to choices in the design of protected areas.

sludge: | A solid or semi-solid precipitate that settles from polluted water during treatment; sludge is produced during the treatment of sewage and also in pulp mills and some other industrial facilities. It may be disposed of in a landfill, but if organic, can be used as a beneficial soil amendment.

smog: | An event of ground-level air pollution.

snag: | A standing dead tree.

social justice: | A worldview that calls for equality of consideration for all members of a society, regardless of colour, race, socio-economic class, gender, age, or sexual preference. See also ecological justice.

socio-cultural evolution: | See cultural evolution.

socio-economic impact assessment: | A process used to identify and evaluate the potential consequences of proposed actions or policies for sociological, economic, and related values. See also environmental impact assessment.

soil profile: | The vertical stratification of soil on the basis of colour, texture, and chemical qualities.

soil: | A complex mixture of fragmented rock, organic matter, moisture, gases, and living organisms that covers almost all of Earth's terrestrial landscapes.

solar energy: | Electromagnetic energy radiated by the sun.

solar system: | The sun, its nine orbiting planets, miscellaneous comets, meteors, and other local materials.

solid wastes: | Extremely variable municipal wastes that include discarded food, garden discards, newspapers, bottles, cans, construction debris, old cars, and disused furniture.

spaceship Earth: | An image of Earth as viewed from space, which illustrates the fact that, except for sunlight, resources needed by humans are present only on that planet.

spaceship world view: | This focuses on sustaining only those resources needed by humans and their economy, and it assumes that humans can exert a great degree of control over natural processes and can pilot "spaceship Earth." See also frontier world view and sustainability world view.

special concern: | Refers to a species that is not currently threatened but is at risk of becoming so for various reasons.

species richness: | The number of species in some area or place.

species: | An aggregation of individuals and populations that can potentially interbreed and produce fertile offspring, and is reproductively isolated from other such groups.

speciesism: | Discrimination (by humans) against other species purely on the basis that they are not human, especially as manifested by cruelty to or exploitation of animals, or merely by a lack of consideration of their interests.

state-of-the-environment reporting: | A governmental, corporate, or NGO function that involves public reporting on environmental conditions.

strategic weapon: | Large explosive-yield weapons that are designed to be delivered by a missile or airplane over a distance of thousands of kilometres. Compare with tactical weapon.

stratosphere: | The upper atmosphere, extending above the. from 8-17 km to as high as about 50 km. See also troposphere.

stress-tolerator: | Long-lived plants adapted to habitats that are marginal in terms of climate, moisture, or nutrient supply, but are infrequently disturbed and therefore stable, such as tundra and desert.

stressor: | An environmental factor that constrains the development and productivity of organisms or ecosystems.

succession: | A process of community- level recovery following disturbance.

surface flow: | Water that moves over the surface of the ground.

surface water: | Water that occurs in glaciers, lakes, ponds, rivers, streams, and other surface bodies of water.

sustainability world view: | This acknowledges that humans must have access to vital resources, but it asserts that the exploitation of resources should be governed by appropriate ecological, aesthetic, and moral values, and should not deplete the necessary resources. See also frontier world view and spaceship world view.

sustainable development: | Refers to progress toward an economic system that uses natural resources in ways that do not deplete their stocks or compromise their availability to future generations.

sustainable economic system (sustainable economy): | An economic system that can be maintained over time without any net consumption of natural resources.

swamp: | A forested wetland, flooded seasonally or permanently.

symbiosis: | An intimate relationship between different species. See also mutualism.

synecology: | The study of relationships among species within communities. Compare with autecology.

system: | A group or combination of regularly interacting and interdependent elements, which form a collective entity, but one that is more than the sum of its constituents. See also ecosystem.

tactical weapon: | Smaller, numerous weapons that are intended for use in a local battlefield, and are delivered by smaller missiles, artillery, aircraft, or torpedoes. Compare with strategic weapon.

taiga: | See boreal forest.

tectonic force: | Force associated with crustal movements and related geological processes that cause structural deformations of rocks and minerals.

temperate deciduous forest: | A forest occurring in relatively moist, temperate climates with short and moderately cold winters and warm summers, and usually composed of a mixture of angiosperm tree species.

temperate grassland: | Grass-dominated ecosystems occurring in temperate regions with an annual precipitation of 25–60 cm per year; sufficient to prevent desert from developing but insufficient to support forest.

temperate rainforest: | A forest developing in a temperate climate in which winters are mild and precipitation is abundant year-round. Because wildfire is rare, old-growth forests may be common.

temperature inversion: | See atmospheric inversion.

teratogen: | A chemical or physical agent that induces a developmental abnormality (i.e., a birth defect) in an embryo or fetus.

tertiary sewage treatment: | Treatment applied to the effluent of secondary sewage treatment, usually involving a system to remove phosphorus and/or nitrogen from waste waters. See also primary sewage treatment and secondary sewage treatment.

theory: | A general term that refers to a set of scientific laws, rules, and explanations supported by a large body of experimental and observational evidence, all leading to robust, internally consistent conclusions.

thermal pollution: | An increase in environmental temperature sufficient to result in ecological change.

thermosphere: | The layer of the atmosphere extending beyond the mesosphere to 450 km or more above the surface of the Earth. See also mesosphere.

threatened: | In Canada, this refers to any indigenous taxa likely to become endangered (in Canada) if factors affecting their vulnerability are not reversed.

tidal energy: | Energy that develops in oceanic surface waters because of the gravitational attraction between Earth and the Moon, and can potentially be used to generate electricity.

tilth: | The physical structure of soil, closely associated with the concentration of humified organic matter. Tilth is important in water- and nutrient-holding capacity of soil, and is generally beneficial to plant growth.

tolerance: | In ecotoxicology, this refers to a genetically based ability of organisms or species to not suffer toxicity when exposed to chemicals or other stressors.

total concentration: | The concentrations of metals in soil, sediment, rocks, or water, as determined after dissolving samples in a strongly acidic solution. Compare with available concentration.

total energy production: | The use of commercial energy plus traditional fuels in an economy. See also traditional fuels.

total-war economy: | An economy that is wholly dedicated to supporting a war effort.

toxic waste: | Waste that is poisonous to humans, animals, or plants. See also hazardous waste.

toxicology: | The science of the study of poisons, including their chemical nature and their effects on the physiology of organisms. Compare with environmental toxicology and ecotoxicology.

traditional fuels: | The non-commercial use of wood, charcoal, animal dung, and other biomass fuels for subsistence purposes, primarily for cooking food and heating homes. See also total energy production and commercial energy production.

transcription: | A biochemical process by which the information of double-stranded DNA is encoded on complementary single strands of RNA, which are used to synthesize specific proteins.

translation: | A biochemical process occurring on organelles known as ribosomes, in which information encoded in messenger RNA is used to synthesize particular proteins.

transpiration: | The evaporation of water from plants. Compare with evapotranspiration.

trophic structure: | The organization of productivity in an ecosystem, including the roles of autotrophs, herbivores, carnivores, and detritivores.

troposphere: | The lower atmosphere, extending to 8–17 km.

tsunami: | A fast-moving, sea-wave caused by an undersea earthquakes, which if large can cause enormous destruction of low-lying coastal places.

tundra: | A treeless biome occurring in environments with long, cold winters and short, cool growing seasons.

unexploded ordinance (UXOs): | Explosives that remain in place after a conflict has ended.

urban agglomeration: | See megacity

urban forest: | Urban areas having a substantial density and biomass of trees, although often most are non-native species.

urban planning: | An active process of designing better ways of organizing the structure and function of cities, including an orderly siting of land uses and activities.

urbanization: | The development of cities and towns on formerly agricultural or natural lands.

utilitarian value: | The usefulness of a thing or function to humans.

value added: | The increased value of something as a result of manufacturing or some other improvement.

valued ecosystem components (VECs): | In environmental impact assessment, these are components of ecosystems perceived to be important to society as economically important resources, as rare or endangered species or communities, or for their cultural or aesthetic significance.

variable: | A changeable factor believed to influence a natural phenomenon of interest or that can be manipulated during an experiment.

vascular plant: | Relatively complex plants with specialized, tube-like vascular tissues in their stems for conducting water and nutrients.

VECs: | See valued ecosystem components.

vector: | Species of insects and ticks that transmit pathogens from alternate hosts to people or animals.

vertebrate: | Animals with an internal skeleton, and in particular a backbone.

virgin field: | In epidemiology, this is a population that is hypersensitive to one or more infectious diseases to which it has not been previously exposed.

volatile organic compounds: | Organic compounds that evaporate to the atmosphere at typical environmental temperatures, so they are present in gaseous or vapour forms.

volcano: | An opening in Earth's crust from which magmic materials, such as lava, rock fragments, and gases, are ejected into the atmosphere or oceanic waters.

war: | A period of organized deadly conflict between human societies, countries, or another defined group.

waste management: | The handling of discarded materials using various methods. See also dumping, incineration, recycling, composting, reuse, and waste reduction.

waste prevention: | See waste reduction.

waste reduction: | Practices intended to reduce the amount of waste that must be disposed of. Also known as waste prevention.

waste-to-energy facility: | An incinerator that burns organic waste and uses the heat generated to produce commercial energy.

waste: | Any discarded materials. See also hazardous waste and toxic waste.

water cycle: | See hydrologic cycle.

watershed: | An area of land from which surface water and groundwater flow into a stream, river, or lake.

wave energy: | The kinetic energy of oceanic waves, which can be harnessed using specially designed buoys to generate electricity.

weather: | The short-term, day-to-day or instantaneous meteorological conditions at a place or region. Compare with climate.

weathering: | Physical and chemical processes by which rocks and minerals are broken down by such environmental agents as rain, wind, temperature changes, and biological influences.

weed: | An unwanted plant that interferes with some human purpose.

wet deposition: | Atmospheric inputs of chemicals with rain and snow. Compare with dry deposition.

wetland: | An ecosystem that develops in wet places and is intermediate between aquatic and terrestrial ecosystems. See also bog, fen, marsh, and swamp.

whole-lake experiment: | The experimental manipulation of one or more environmental factors in an entire lake.

wind energy: | The kinetic energy of moving air masses, which can be tapped and utilized in various ways, including the generation of electricity.

wind: | An air mass moving in Earth's atmosphere.

work: | In physics, work is defined as the result of a force being applied over a distance.

working hypothesis: | A hypothesis being tested in a scientific experiment or another kind of research. See also hypothesis and null hypothesis.

zero population growth (ZPG): | When the birth rate plus immigration equal the death rate plus emigration.

zooplankton: | Tiny animals that occur in the water column of lakes and oceans

Glossary

Sample Word 1 | Sample Definition 1

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  - Front Matter - *Undeclared*
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  - 1: Environmental Science - *CC BY 4.0*
    - Page 1.1: The Earth, Humans, and the Environment - *CC BY 4.0*
    - Page 1.2: The Process of Science - *CC BY 4.0*
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    - Page 1.S: Environmental Science (Summary) - *CC BY 4.0*
  - 2: The Physical World - *CC BY-NC 4.0*
  - 3: Matter, Energy, and Life - *CC BY 4.0*
    - Page 3.1: Matter - *CC BY 4.0*
    - Page 3.2: Energy - *CC BY 4.0*
    - Page 3.3: A Cell is the Smallest Unit of Life - *CC BY 4.0*
    - Page 3.4: Energy Enters Ecosystems Through Photosynthesis - *CC BY 4.0*
    - Page 3.5: Energy Flow through Ecosystems - *CC BY 4.0*
    - Page 3.6: Biogeochemical Cycles - *CC BY 4.0*
    - Page 3.S: Matter, Energy, and Life (Summary) - *CC BY 4.0*
  - 4: Biomes and the Biosphere - *CC BY 4.0*
    - Page 4.1: Terrestrial Biomes - *CC BY 4.0*
    - Page 4.2: Aquatic Biomes - *CC BY 4.0*
    - Page 4.3: Chapter Resources - *CC BY 4.0*
  - 5: Community and Population Ecology - *CC BY 4.0*
    - Page 5.1: Population Demographics and Dynamics - *CC BY 4.0*
    - Page 5.2: Population Growth and Regulation - *CC BY 4.0*
    - Page 5.3: The Human Population - *CC BY 4.0*
    - Page 5.4: Community Ecology - *CC BY 4.0*
    - Page 5.5: Chapter Resources - *CC BY 4.0*
  - 6: Conventional and Sustainable Energy - *CC BY 4.0*
    - Page 6.1: Challenges and Impacts of Energy Use - *CC BY 4.0*
    - Page 6.2: Non-Renewable Energy Sources - *CC BY 4.0*
    - Page 6.3: Renewable Energy Sources - *CC BY 4.0*
    - Page 6.4: Chapter Resources - *CC BY 4.0*
  - 7: Conservation and Biodiversity - *CC BY 4.0*
    - Page 7.1: Introduction to Biodiversity - *CC BY 4.0*
    - Page 7.2: Origin of Biodiversity - *CC BY 4.0*
    - Page 7.3: Importance of Biodiversity - *CC BY 4.0*
    - Page 7.4: Threats to Biodiversity - *CC BY 4.0*
    - Page 7.5: Preserving Biodiversity - *CC BY 4.0*
    - Page 7.6: Chapter Resources - *CC BY 4.0*
  - 8: Environmental Hazards and Human Health - *CC BY 4.0*
    - Page 8.1: The Impacts of Environmental Conditions - *CC BY 4.0*
    - Page 8.2: Environmental Health - *CC BY 4.0*
    - Page 8.3: Environmental Toxicology - *CC BY 4.0*
    - Page 8.4: Bioremediation - *CC BY 4.0*
    - Page 8.5: Case Study - The Love Canal Disaster - *CC BY 4.0*
    - Page 8.S: Environmental Hazards and Human Health (Summary) - *CC BY 4.0*

- 9: Water Availability and Use - *CC BY 4.0*
  - Page 9.1: Water Cycle and Fresh Water Supply - *CC BY 4.0*
  - Page 9.2: Water Supply Problems and Solutions - *CC BY 4.0*
  - Page 9.3: Water Pollution - *CC BY 4.0*
  - Page 9.4: Water Treatment - *CC BY 4.0*
  - Page 9.5: Case Study - The Aral Sea - Going, Going, Gone - *CC BY 4.0*
  - Page 9.6: Chapter Resources - *CC BY 4.0*
- 10: Food and Hunger - *CC BY 4.0*
  - Page 10.1: Food Security - *CC BY 4.0*
  - Page 10.2: Biotechnology and Genetic Engineering - *CC BY 4.0*
  - Page 10.3: Chapter Resources - *CC BY 4.0*
- 11: Conventional and Sustainable Agriculture - *CC BY 4.0*
  - Page 11.1: Soil Profiles and Processes - *CC BY 4.0*
  - Page 11.2: Soil-Plant Interactions - *CC BY 4.0*
  - Page 11.3: Conventional Agriculture - *CC BY 4.0*
  - Page 11.4: Pests and Pesticides - *CC BY 4.0*
  - Page 11.5: Sustainable Agriculture - *CC BY 4.0*
  - Page 11.S: Conventional and Sustainable Agriculture (Summary) - *CC BY 4.0*
- 12: Environmental Effects of Forestry - *CC BY-NC 4.0*
- 13: Air Pollution, Climate Change, and Ozone Depletion - *CC BY 4.0*
  - Page 13.1: Atmospheric Pollution - *CC BY 4.0*
  - Page 13.2: Ozone Depletion - *CC BY 4.0*
  - Page 13.3: Acid Rain - *CC BY 4.0*
  - Page 13.4: Climate Change - *CC BY 4.0*
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  - Page 14.1: The Human Dimensions of Sustainability- History, Culture, Ethics - *CC BY 4.0*
  - Page 14.2: It's Not Easy Being Green- Anti-Environmental Discourse, Behavior, and Ideology - *CC BY 4.0*
  - Page 14.3: The Industrialization of Nature- A Modern History (1500 to the present) - *CC BY 4.0*
  - Page 14.4: Case Study- Agriculture and the Global Bee Colony Collapse - *CC BY 4.0*
  - Page 14.5: Sustainability Ethics - *Undeclared*
- Back Matter - *Undeclared*
  - Index - *Undeclared*
  - Glossary - *Undeclared*
  - Glossary - *Undeclared*
  - Detailed Licensing - *Undeclared*