INTRODUCTION TO ENVIRONMENTAL SCIENCE



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Northwestern Connecticut Community College

Introduction to Environmental Science

Tara Jo Holmberg

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CHAPTER OVERVIEW

1: Framing Our Study of 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

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1.1: The Earth, Humans, and the Environment

What is Environmental Science?

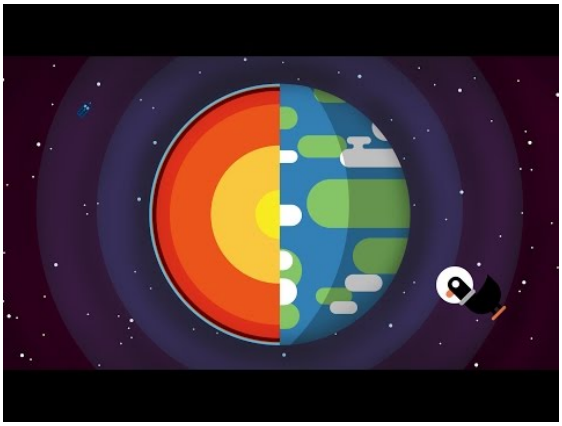
Environmental science is the dynamic, interdisciplinary study of the interaction of living and non-living parts of the environment, with special focus on the impact of humans on the environment. The study of environmental science includes circumstances, objects, or conditions by which an organism or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

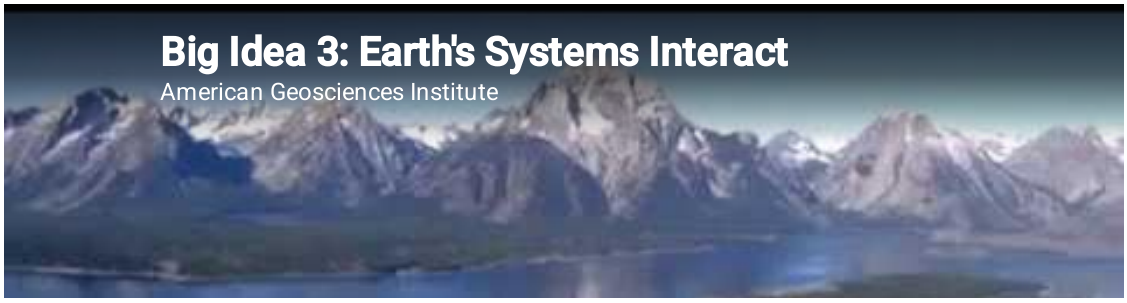
From global climate change to habitat loss driven by human population growth and development, Earth is becoming a different planet—right before our eyes. The global scale and rate of environmental change are beyond anything in recorded human history. Our challenge is to acquire an improved understanding 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:



Perspectives: Earth as a System

The Earth system is a way of describing the entire Earth as a dynamic entity composed of four interconnected and interacting subsystems: the geosphere (land and rocks), the hydrosphere (water), the atmosphere (air), and the biosphere (life). These subsystems are connected by energy and matter cycles, such as the water and carbon cycles, that constantly store, transform, and transfer elements, shaping the planet's environment and processes. An additional subsystem, the anthroposphere (human activity), has substantially altered many of the other natural systems. Much of this text explains the impacts of the anthroposphere and the other Earth 'spheres'.





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1.2: Environmental Laws and Regulations

INTRODUCTION

Although environmental laws are generally considered a 20th century phenomenon, attempts have been made to legislate environmental controls throughout history. In 2,700 B.C., the middle-eastern civilization in Ur passed laws protecting the few remaining forests in the region. In 80 A.D., the Roman Senate passed a law to protect water stored for dry periods so it could be used for street and sewer cleaning. During American colonial times, **Benjamin Franklin** argued for "public rights" laws to protect the citizens of Philadelphia against industrial pollution produced by animal hide tanners.

Significant environmental action began at the beginning of the 20th century. In 1906, Congress passed the “Antiquities Act,” which authorizes the president to protect areas of federal lands as national monuments. A few years later, **Alice Hamilton** pushed for government regulations concerning toxic industrial chemicals. She fought, unsuccessfully, to ban the use of lead in gasoline. She also supported the legal actions taken by women who were dying of cancer from their exposure to the radium then used in glow-in-the-dark watch dials. During the early 1960’s, biologist **Rachel Carson** pointed out the need to regulate pesticides such as DDT to protect the health of wildlife and humans.

With the establishment of the **Environmental Protection Agency (EPA)** in 1970, environmental law became a field substantial enough to occupy lawyers on a full-time basis. Since then, federal and state governments have passed numerous laws and created a vast network of complicated rules and regulations regarding environmental issues. Moreover, international organizations and agencies including the **United Nations**, the **World Bank**, and the **World Trade Organization** have also contributed environmental rules and regulations.

Because of the legal and technical complexities of the subjects covered by environmental laws, persons dealing with such laws must be knowledgeable in the areas of law, science and public policy. Environmental laws today encompass a wide range of subjects such as air and water quality, hazardous wastes and biodiversity. The purpose of these environmental laws is to prevent, minimize, remedy and punish actions that threaten or damage the environment and those that live in it. However, some people believe that these laws unreasonably limit the freedom of people, organizations, corporations and government agencies by placing controls on their actions.

HISTORIC U.S. FEDERAL LAWS

Early attempts by Congress to enact laws affecting the environment included the **Antiquities Act** in 1906, the **National Park Service Act** in 1916, the **Federal Insecticide**, **Fungicide and Rodenticide Act** in 1947 and the **Water Pollution Control Act** in 1956. The **Wilderness Act** of 1964, protected large areas of pristine federal lands from development and ushered in the new age of environmental activism that began in the 1960’s. However, it was the **National Environmental Policy Act (NEPA)** enacted in 1969 and the formation of the Environmental Protection Agency (EPA) in 1970 that started environmental legislation in earnest. The main objective of these two federal enactments was to assure that the environment would be protected from both public and private actions that failed to take into account the costs of damage inflicted on the environment.

Many consider NEPA to be the most far-reaching environmental legislation ever passed by Congress. The basic purpose of NEPA is to force governmental agencies to comprehensively consider the effects of their decisions on the environment. This is effected by requiring agencies to prepare detailed **Environmental Impact Statements** (EIS) for proposed projects. The EPA is the government's environmental watchdog. It is charged with monitoring and analyzing the state of the environment, conducting research, and working closely with state and local governments to devise pollution control policies. The EPA is also empowered to enforce those environmental policies. Unfortunately, the agency is sometimes caught up in conflicts between the public wanting more regulation for environmental reasons and businesses wanting less regulation for economic reasons. Consequently, the development of a new regulation can take many years.

Since 1970, Congress has enacted several important environmental laws, all of which include provisions to protect the environment and natural resources. Some of the more notable laws include:

- The **Federal Clean Air Act** (1970, 1977 & 1990) established national standards for regulating the emission of pollutants from stationary and mobile sources.

- The **Federal Water Pollution Control Act** (1972) amended by the **Clean Water Act** (1977, 1987), established water quality standards; provides for the regulation of the discharge of pollutants into navigable waters and for the protection of wetlands.
- The **Federal Safe Drinking Water Act** (1974, 1977 & 1986) set drinking water standards for levels of pollutants; authorizing the regulation of the discharge of pollutants into underground drinking water sources.
- The **Toxic Substances Control Act** (1976) provided for the regulation of chemical substances by the EPA and the safety testing of new chemicals.
- The **Resource Conservation and Recovery Act** (1976) established cradle-to-grave regulations for the handling of hazardous wastes.
- The **Comprehensive Environmental Response**, **Compensation and Liability Act** (1980), also known as the **Superfund** program, provided for the cleanup of the worst toxic waste sites.
- The **Food Security Act** (1985, 1990) later amended by the **Federal Agriculture Improvement and Reform Act** (1996), discouraged cultivation of environmentally sensitive lands, especially wetlands, and authorized incentives for farmers to withdraw highly erodible lands from production.

The application, or enforcement, of an environmental law is not always straightforward, and problems can arise. Often, the biggest problem is that Congress fails to allocate the funds necessary for implementing or enforcing the laws. Administrative red tape may make it impossible to enforce a regulation quickly. It may also be unclear as to which agency (or branch of an agency) is responsible for enforcing a particular regulation. Furthermore, agency personnel decline to enforce a regulation for political reasons.

Numerous alterations to federal laws are currently being made in real time. These will be covered as the course progresses.

U.S. STATE LAWS

Most states, like California, have enacted their own environmental laws and established agencies to enforce them. California faced some of its first environmental challenges in the mid-1800's, with regard to debris from the hydraulic mining of gold. Water quality concerns, dangers of flooding, negative impact on agriculture and hazards to navigation prompted the state to act.

Some of California's environmental regulations preceded similar federal laws and California continues to set many of the standards for environmental laws currently. For example, California established the nation's first air quality program in the 1950s. Much of the federal Clean Air Act amendments of 1990 were based upon the **California Clean Air Act of 1988**. California also pioneered advances in vehicle emission controls, control of toxic air pollutants and control of stationary pollution sources before federal efforts in those areas. The **Porter-Cologne Act of 1970**, upon which the state's water quality program is based, also served as the model for the federal Clean Water Act.

California's state environmental regulations are sometimes more stringent than the federal laws (e.g., the California Clean Air Act and vehicle emissions standards). In other program areas, no comparable federal legislation exists. For example, the California **Integrated Waste Management Act** established a comprehensive, statewide system of permitting, inspections, enforcement and maintenance for solid waste facilities and sets minimum standards for solid waste handling and disposal to protect air, water and land from pollution. Also, **Proposition 65** (**Safe Drinking Water and Toxic Enforcement Act**) requires the Governor to publish a list of chemicals that are known to the State of California to cause cancer, birth defects or other reproductive harm.

Despite the state's leadership in environmental programs and laws, the creation of a cabinet-level environmental agency in California lagged more than two decades behind the establishment of the federal EPA. Originally, organization of California's environmental quality programs was highly fragmented. Each separate program handled a specific environmental problem (e.g., the **Air Resources Board**), with enforcement responsibility falling to both state and local governments. It was not until 1991 that a California EPA was finally established and united the separate programs under one agency.

INTERNATIONAL TREATIES AND CONVENTIONS

Conventions, or treaties, generally set forth international environmental regulations. These conventions and treaties often result from efforts by international organizations such as the **United Nations (UN)** or the **World Bank**. However, it is often difficult, if not impossible, to enforce these regulations because of the sovereign rights of countries. In addition rules and regulations set forth

in such agreements may be no more than non-binding recommendations, and often countries are exempted from regulations due to economic or cultural reasons. Despite these shortcomings, the international community has achieved some success via its environmental agreements. These include an international convention that placed a moratorium on whaling (1986) and a treaty that banned the ocean dumping of wastes (1991).

The UN often facilitates international environmental efforts. In 1991, the UN enacted an **Antarctica Treaty**, which prohibits mining of the region, limits pollution of the environment and protects its animal species. The United Nations Environment Program (UNEP) is a branch of the UN that specifically deals with worldwide environmental problems. It has helped with several key efforts at global environmental regulations:

- **The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer**. As a result of this global agreement, industrialized countries have ceased or reduced the production and consumption of ozone-depleting substances such as chlorofluorocarbons.
- **The Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade**. This agreement enhances the world's technical knowledge and expertise on hazardous chemicals management.
- **The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)**. This agreement protects over 30,000 of the world's endangered species.
- In 1995 **UNEP and the International Olympic Committee (IOC)** signed a partnership agreement to develop environmental guidelines for sports federations and countries bidding to host the Olympic games.
- **The Rotterdam Convention** (1998) addressed the growing trade in hazardous pesticides and chemicals. Importing countries must now give explicit informed consent before hazardous chemicals can cross their borders.
- **The International Declaration on Cleaner Production** (1998). The signatories commit their countries to implement cleaner industrial production and subsequent monitoring efforts.

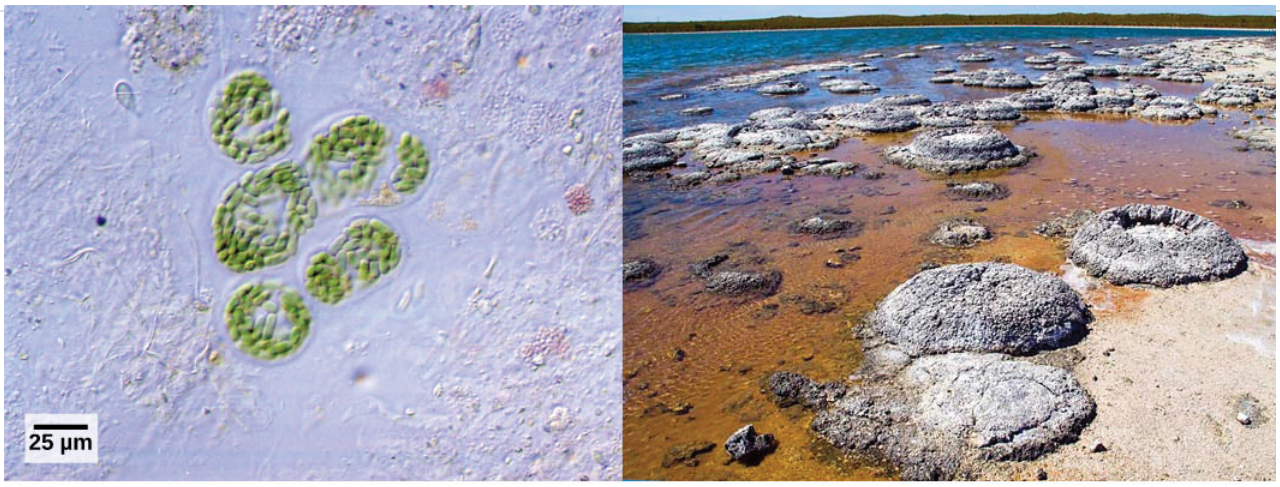
In 1992, the UN member nations committed their resources to limiting greenhouse gas (e.g., carbon dioxide) emissions at or below 1990 levels, as put forth by the **UN Framework Convention on Climate Change**. Unfortunately, the agreement was non-binding and by the mid-1990's, it had had no effect on carbon emissions. The 1997 **Kyoto Protocol** was a binding resolution to reduce greenhouse gases. Although the United States initially supported the resolution, the Senate failed to ratify the treaty, and by 2001 the resolution was opposed by President Bush as threatening the United States economy. Unfortunately, many of the US's actions in international climate policy have been similar over the following 25 years.

Additional climate treaties will be discussed later in this text, as will other international conventions.

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1.3: The Process of Science



(a) (b)

Figure 1.3.1. (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.

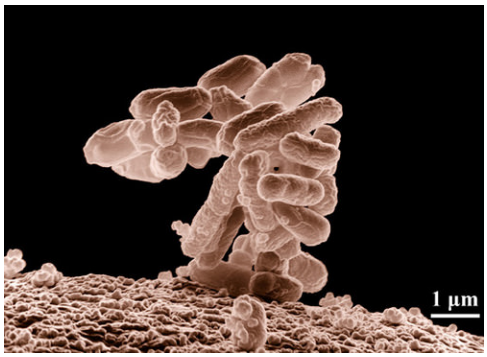


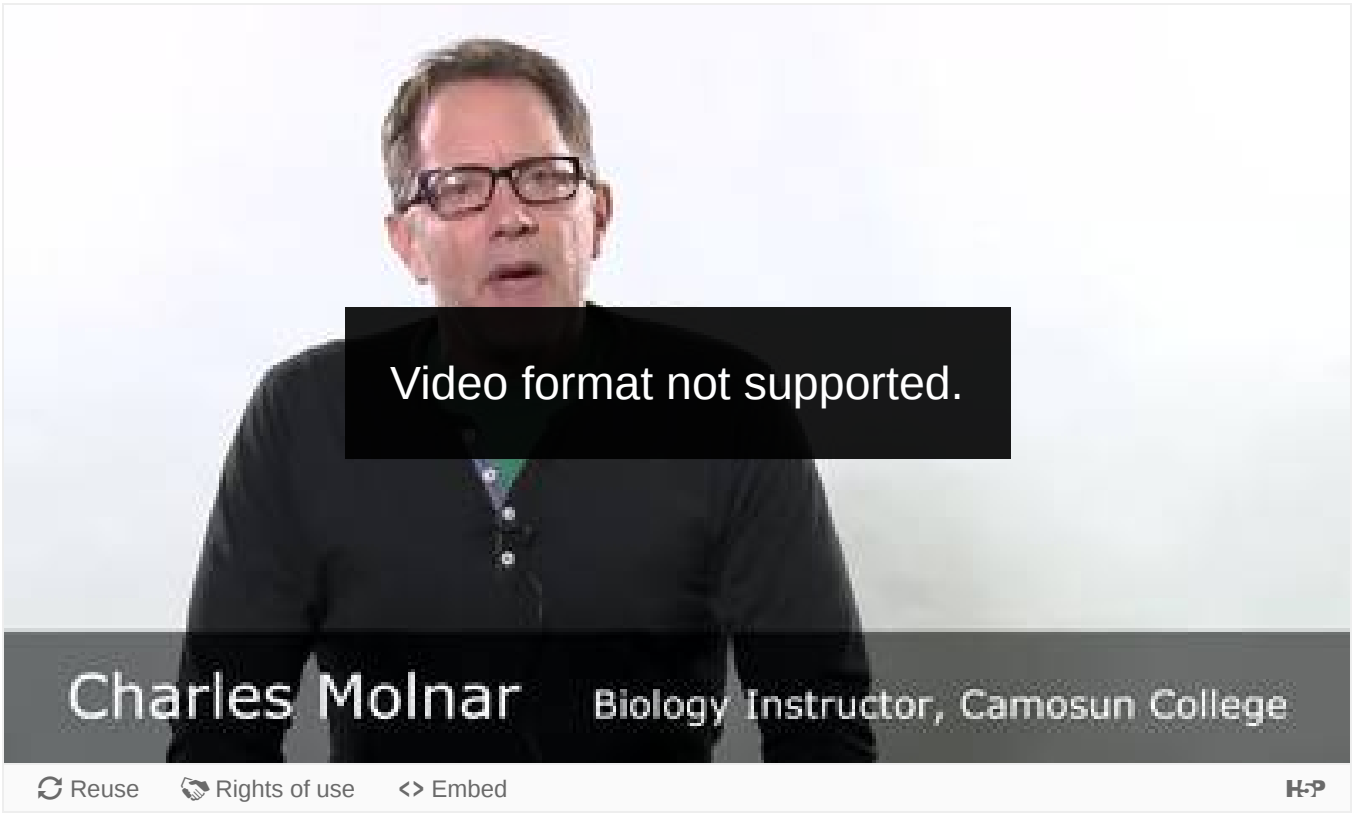
Figure 1.3.2. Biologists may choose to study Escherichia coli (E. coli), a bacterium that is a normal resident of our digestive tracts but which is also sometimes responsible for disease outbreaks. In this micrograph, the bacterium is visualized using a scanning electron microscope and digital colorization. (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.



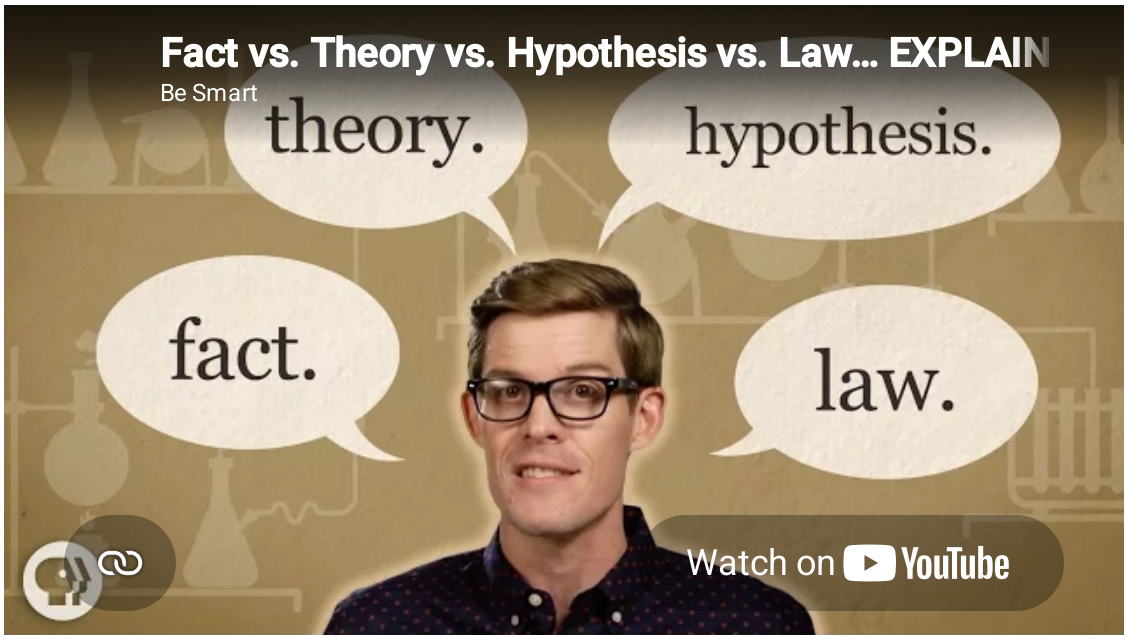
Figure 1.3.3. Sir Francis Bacon is credited with being the first to document the scientific method.

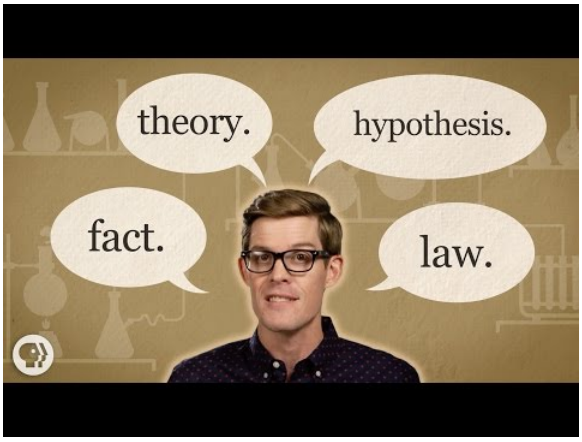
The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. One Monday morning, a student arrives at class and quickly discovers 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 1.3.3). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

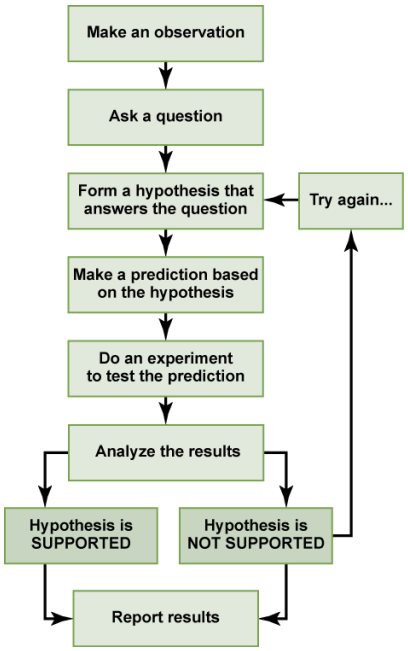


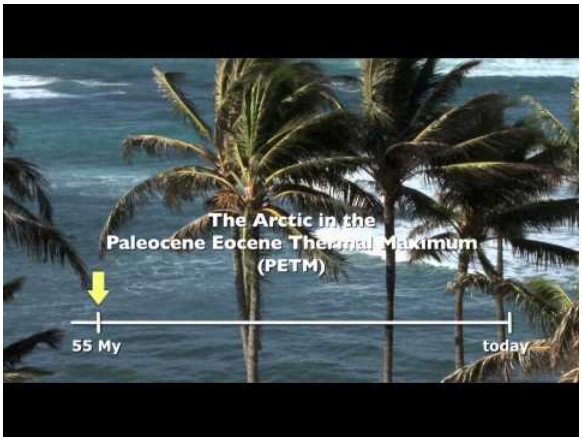
Figure 1.3.4. The scientific method is a series of defined steps that include experiments and careful observation. If a hypothesis is not supported by data, a new hypothesis can be proposed.

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 1.3.5) 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.

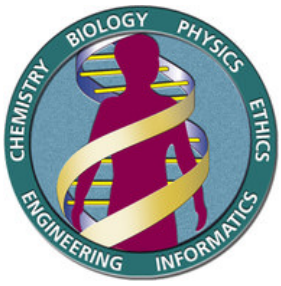


Figure 1.3.5. The Human Genome Project was a 13-year collaborative effort among researchers working in several different fields of science. The project was completed in 2003. (credit: the U.S. Department of Energy Genome Programs)

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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1.4: Pseudoscience and Other Misuses of Science

What Is Pseudoscience?

Pseudoscience is a claim, belief, or practice that is presented as scientific but does not adhere to the standards and methods of science. True science is based on repeated evidence-gathering and testing of falsifiable hypotheses. Pseudoscience does not adhere to these criteria. In addition to phrenology, some other examples of pseudoscience include astrology, extrasensory perception (ESP), reflexology, reincarnation, and Scientology,

Characteristics of Pseudoscience

Whether a field is actually science or just pseudoscience is not always clear. However, pseudoscience generally exhibits certain common characteristics. Indicators of pseudoscience include:

- **The use of vague, exaggerated, or untestable claims:** Many claims made by pseudoscience cannot be tested with evidence. As a result, they cannot be falsified, even if they are not true.
- **An over-reliance on confirmation rather than refutation:** Any incident that appears to justify a pseudoscience claim is treated as proof of the claim. Claims are assumed true until proven otherwise, and the burden of disproof is placed on skeptics of the claim.
- **A lack of openness to testing by other experts:** Practitioners of pseudoscience avoid subjecting their ideas to peer review. They may refuse to share their data and justify the need for secrecy with claims of proprietary or privacy.
- **An absence of progress in advancing knowledge:** In pseudoscience, ideas are not subjected to repeated testing followed by rejection or refinement, as hypotheses are in true science. Ideas in pseudoscience may remain unchanged for hundreds, or even thousands, of years. In fact, the older an idea is, the more it tends to be trusted in pseudoscience.
- **Personalization of issues:** Proponents of pseudoscience often adopt beliefs that have little or no rational basis, so they may attempt to confirm their beliefs by treating critics as adversaries. Instead of arguing to support their own beliefs, they attack the motives and character of their critics.
- **The use of misleading language:** Followers of pseudoscience may employ scientific-sounding terms to lend their ideas a more convincing appearance. For example, they may use the formal name dihydrogen monoxide to refer to plain old water.

Video





This 6-minute video identifies three questions to ask yourself before believing something.
Question after watching: What are some instances of pseudoscience that you have seen or heard recently?

Persistence of Pseudoscience

Despite failing to meet scientific standards, many pseudosciences survive. Some pseudosciences remain very popular with large numbers of believers. A good example is astrology.

Astrology is the study of the movements and relative positions of celestial objects as a means for divining information about human affairs and terrestrial events. Many ancient cultures attached importance to astronomical events, and some developed elaborate systems for predicting terrestrial events from celestial observations. Throughout most of its history, astrology has been regarded as scholarly and was widely accepted in academic circles. With the advent of the modern scientific process, astrology was called into question. It was challenged on both theoretical and experimental grounds, and it was eventually shown to have no scientific validity or explanatory power.

Today, astrology is often considered a pseudoscience, yet it remains a subject of devotion among many. Most people know their astrological sign, and many people are familiar with the personality traits supposedly associated with their sign. Astrological readings and horoscopes are readily available online and in print media, and a lot of people read them, even if only occasionally. About a third of all adult Americans actually believe that astrology is scientific. Studies suggest that the persistent popularity of pseudosciences, such as astrology, reflects a high level of scientific illiteracy, indicating that the public generally lacks a clear understanding of scientific principles and methodology. They are not convinced by scientific arguments against their beliefs.

Dangers of Pseudoscience

Belief in astrology is unlikely to cause a person harm, but belief in some other pseudosciences might — especially in health care-related areas. Treatments that seem scientific but are not may be ineffective, expensive, and even dangerous to patients. Seeking out pseudoscientific treatments may also delay or preclude patients from seeking scientifically-based medical treatments that have been tested and found safe and effective. In short, irrational health care may not be harmless.

Scientific Hoaxes, Frauds, and Fallacies

Pseudoscience is not the only way that science may be misused. Scientific **hoaxes,** frauds, and fallacies may misdirect the pursuit of science, put patients at risk, or mislead and confuse the public. Examples of each of these misuses of science and their negative effects are described below.

The Vaccine-Autism Fraud

While it is not true, you may have heard that certain vaccines put the health of young children at risk. This persistent idea is not supported by scientific evidence or accepted by the vast majority of experts in the field. It stems largely from an elaborate medical research fraud that was reported in a 1998 article published in the respected British medical journal, *The Lancet*. The main author of the article was a British physician named Andrew Wakefield. In the article, Wakefield and his colleagues described case histories of only 12 children, most of whom were reported to have developed autism soon after the administration of the MMR (measles, mumps, rubella) vaccine.

There were a range of problems with this study, including falsification of research, ethics violations, and issues with the experimental design. The paper has been retracted (a very big deal in the science community), most of the co-authors have retracted their authorship, and Wakefield lost his medical license. It also later emerged that Wakefield had received research funding from a group of people who were suing vaccine manufacturers. Thousands of follow-up studies have failed to show any association between the MMR vaccine and autism. Unfortunately, by then, the damage had already been done. Parents afraid that their children would develop autism had refrained from having them vaccinated. British MMR vaccination rates fell from nearly 100 percent to 80 percent in the years following the study. The consensus of medical experts today is that Wakefield's fraud put hundreds of thousands of children at risk because of the lower vaccination rates, and also diverted research efforts and funding away from finding the true cause of autism.

Correlation-Causation Fallacy

Many statistical tests used in scientific research calculate correlations between variables. **Correlation** refers to the degree to which two data sets are related, which can be a useful starting point for further investigation. Correlation, however, is also one of the most misused types of evidence, primarily because of the logical fallacy that correlation

implies causation. In reality, just because two variables are correlated does not *necessarily* mean that either variable causes the other.

A few simple examples, illustrated by the graphs below, can be used to demonstrate the correlation-causation fallacy. Assume a study found that both per capita consumption of mozzarella cheese and the number of Civil Engineering doctorates awarded are correlated; that is, rates of both events increase together. Figure 1.4.4. If correlation really did imply causation, then you could conclude from the second example that the increase in age of Miss America causes an increase in murders of a specific type or vice versa Figure 1.4.5.

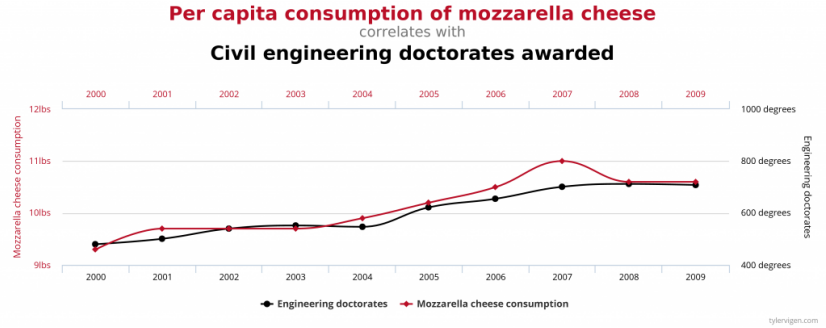


Figure 1.4.4 Spurious Correlations [Causation Fallacy] – Consumption of mozzarella cheese and awarded Doctorates

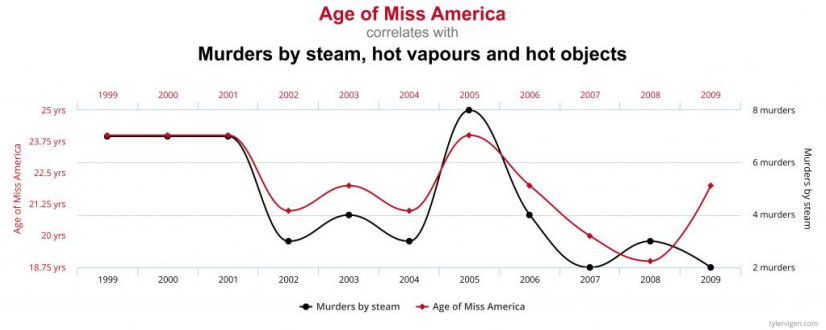


Figure 1.4.5: Spurious Correlations (Causation Fallacy)- Miss America and Murder

Video





Watch this 4-minute video to learn how to spot a misleading graph.
Question after watching: How can graphs present an opinion?

HRT and CHD

An actual example of the correlation-causation fallacy occurred during the latter half of the 20th century. Numerous studies showed that women taking hormone replacement therapy (HRT) to treat menopausal symptoms also had a lower-than-average incidence of coronary heart disease (CHD). This correlation was misinterpreted as evidence that HRT protects women against CHD. Subsequent studies that controlled other factors related to CHD disproved this presumed causal connection. The studies found that women taking HRT were more likely to come from higher socio-economic groups, with better-than-average diets and exercise regimens. Rather than HRT causing lower CHD incidence, these studies concluded that HRT and lower CHD were both effects of higher socio-economic status and related lifestyle factors.

Video





How statistics can be misleading
Question after watching:
What types of motivation could be at play when people or organizations present statistics?

Finally, read through this “Rough Guide to Spotting Bad Science” infographic from Compound Interest:

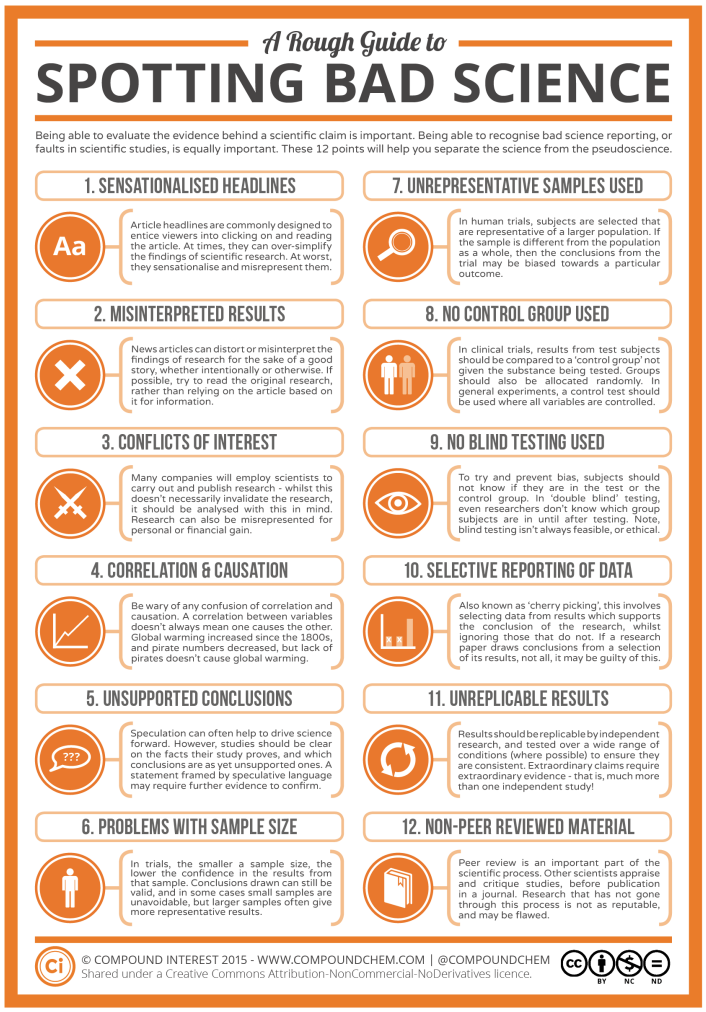


Figure 1.4.6: A Rough Guide to Spotting Bad Science.

Attributions

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1.5: Environment and Sustainability

Introduction

The study of environmental science is interdisciplinary. It is important to understand how and why the environmental movement started, and to know the historical contributions many individuals have made.

Our society and planet will continue to face many environmental problems. Global climate change, habitat alteration, deforestation, the many forms of pollution, and food production are just a few of the myriad issues challenging the conservation of the environment. We all need to take ownership of the environmental issues and promote solutions to these problems.

The ideas of social justice, sustainable development, and sustainability are all integral to environmental science. Keep these in mind throughout the course!

Important Terms throughout the Course

Conservationist: someone who advocates or practices the sensible and careful use of natural resources
Preservationist: someone who advocates allowing some land and some creatures to exist without significant human interference
Environmentalist: someone who is concerned about the impact of people on environmental quality
Ecologist: a scientist who studies the relationships between organisms and their environments.





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 on the wide diversity of other species that also depend on them.

Evolution normally generates new lifeforms at a rate that outstrips the extinction of other species, resulting in strong biological diversity. However, scientists have evidence that, for the first time in known evolutionary history, another species — *Homo sapiens* — has upset this balance to the point that the rate of species extinction is now estimated to be 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 pollutants in the stratosphere to the artificially altered courses of most 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 correct, the rate, scale, and nature of human-induced global change — particularly in the post-industrial period — are unprecedented in the history of life on Earth.

There are three primary reasons for this:

Firstly, the mechanization of both industry and agriculture in the last century vastly improved labor productivity, enabling the creation of goods and services. Since then, scientific advances and technological innovations — 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 have generated material flows of an unprecedented scale. The Wuppertal Institute estimates that humans are now responsible for moving more matter across the planet than all natural processes (earthquakes, storms, etc.) combined.

Secondly, the sheer size of the human population is unprecedented. Every passing year adds another 90 million people to the planet. Even though environmental impacts vary 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 the forefront. 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 current patterns of production and consumption are unsustainable for a global population projected to reach 12 billion by 2050. If ecological crises and rising social conflict are to be 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 scale of change, but also the nature of that change, that are unprecedented. Human inventiveness has introduced chemicals and materials into the environment that 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 to humans and other life forms, let alone for their effects when combined with other chemicals. These issues are now the subject of special UN and other intergovernmental working groups.

The Development of Sustainability as an Idea

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 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 intergenerational 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 undertaken, its potential consequences for the seventh generation had to be considered. For a species that is currently only 6,000 generations old and whose current political decision-makers operate on time scales of months or a 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.



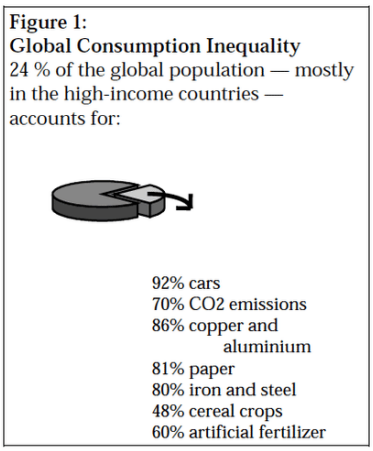






Environmental Equity

While much progress is being made to improve resource efficiency, far less is being made to improve resource distribution. Currently, just one-fifth of the global population is consuming three-quarters of the earth's resources (Figure 1.5.1). 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 inequality and limited purchasing power have prevented poorer countries from reaching the standard of living (and also resource consumption/waste emissions) of the industrialized countries.



Countries such as the so-called BRIC countries of Brazil, Russia, India, and China (along with others like Malaysia) are, however, catching up fast. In such a situation, global consumption of resources and energy needs to be drastically reduced so that it can be sustained 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 issues of fairness and distributional justice remain unresolved.




Population growth, environmental degradation and
UN DESA
Watch on YouTube




Child Mortality in Developing Countries
Gates Foundation
1983
child mortality
30%
20%
10%
0%
1
2
3
4
5
babies born per woman
Watch on YouTube







Concepts in Environmental Science

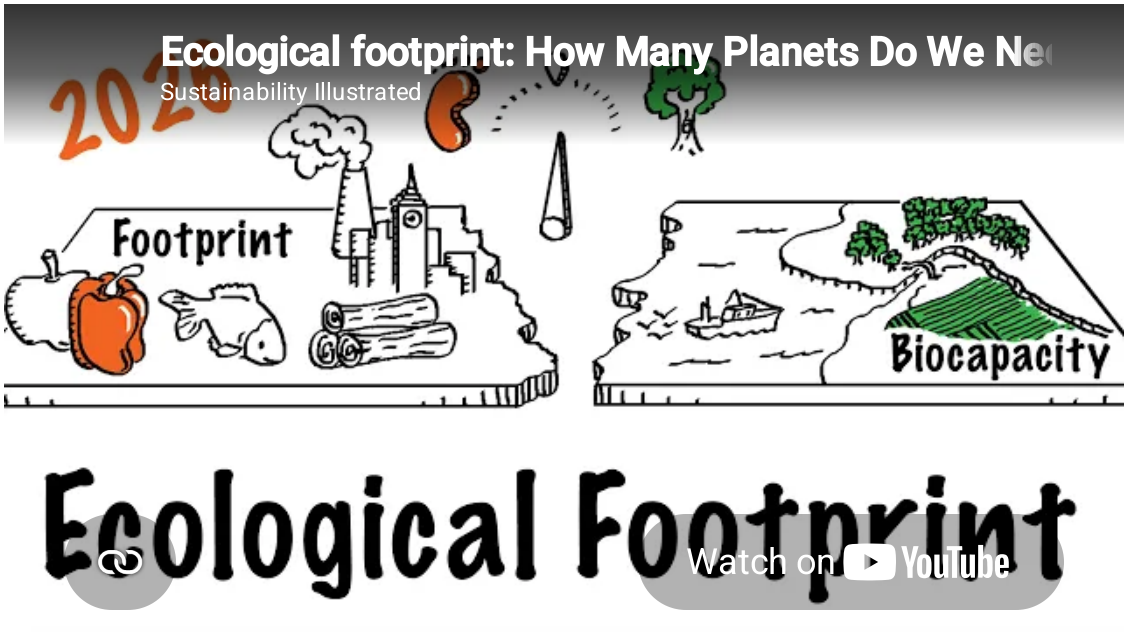
The **ecological footprint** (EF), developed by Canadian ecologist and planner William Rees, is basically an accounting tool that uses land as the unit of measurement to assess per capita consumption, production, and discharge needs. It starts from the assumption that every category of energy and material 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

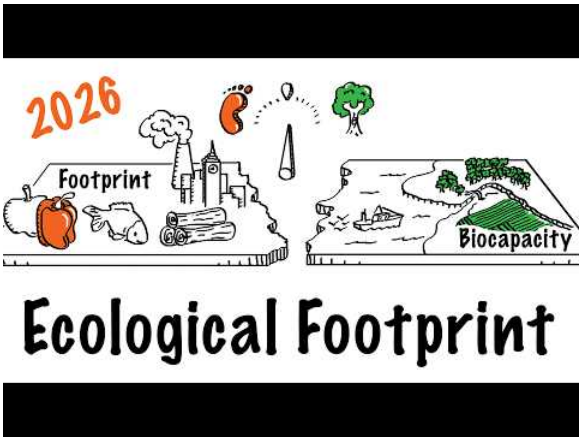
discharge by a defined population, the total area represents the Ecological Footprint of that population on Earth, whether or not this area coincides with the population's home region.

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 required 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 (or around 2.2 football fields) per capita of productive land. With roughly 7.4 billion hectares of Earth's total surface area of 51 billion hectares available for human consumption, if the current global population were to adopt the consumer lifestyle of Americans, 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 is developed, 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 yet been proven. 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

Below are just some of the indicators of global environmental stress. Each of these, and others, will be covered in more detail throughout this text, as well as possible solutions.

Atmosphere

The Intergovernmental Panel on Climate Change has established that human activities are having a discernible influence on the global climate. CO_2 emissions in most industrialized countries have risen over 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.

Biodiversity

Biodiversity is increasingly threatened by development, which destroys or degrades natural habitats, and by pollution from various sources. The first comprehensive global assessment of biodiversity estimated 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 with extinction each decade. Coastal ecosystems, which host a very large proportion of marine species, are at great risk, with perhaps 33% of the world's coasts at high potential risk of degradation and another 17% at moderate risk.

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 occurring in 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). To maintain current per capita fish consumption, global fish harvests must increase; much of this increase might come from aquaculture, which is a known source of water pollution, wetland loss, and mangrove destruction.

Toxic chemicals

More than 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 worldwide, both in absolute and per capita terms. In the developed world, per capita waste generation has increased threefold over the past 20 years; in developing countries, it is highly likely to double over 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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1.6: Environmental Ethics

Utilitarianism (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.

Sustainability 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)

Case Study: 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 1.6.1. 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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1.7: 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 1.7.1. 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.


Ecuador: 'Toxic Tours' reveal damage done by Che
FRANCE 24 English
France 24 is a French public broadcast service.
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Indigenous Communities Are on the Front Lines of
Hot Mess
CLIMATE
CHANGE
AND INDIGENOUS
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PEOPLE


The importance of indigenous rights and knowledg
IUCN, International Union for Conservation of Nature
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create change
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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

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

Answer

A. Basic Science

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.

Answer

C. Introducing invasive species will decrease biodiversity by displacing native species.

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

Answer

C. Sustainable logging of a forest

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

Answer

B. Precautionary principle

The equal sharing of Earth's resources is specifically known as…

A. Environmental justice
B. Sustainability
C. Environmental equity
D. Ecological footprinting
E. Mutualism

Answer

B. Environmental equity

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

Answer

B. Land ethic

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.

Answer

A. Every lion you've seen on TV hunts gazelles, therefore all lions hunt gazelles.

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

Answer

B. Environmental justic

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

Answer

B. Indigenous

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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CHAPTER OVERVIEW

11: 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

11.1: Atmospheric Pollution

11.2: Ozone Depletion

11.3: Acid Rain

11.4: Revisiting Climate Change

11.5: Chapter Resources

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11.1: 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.



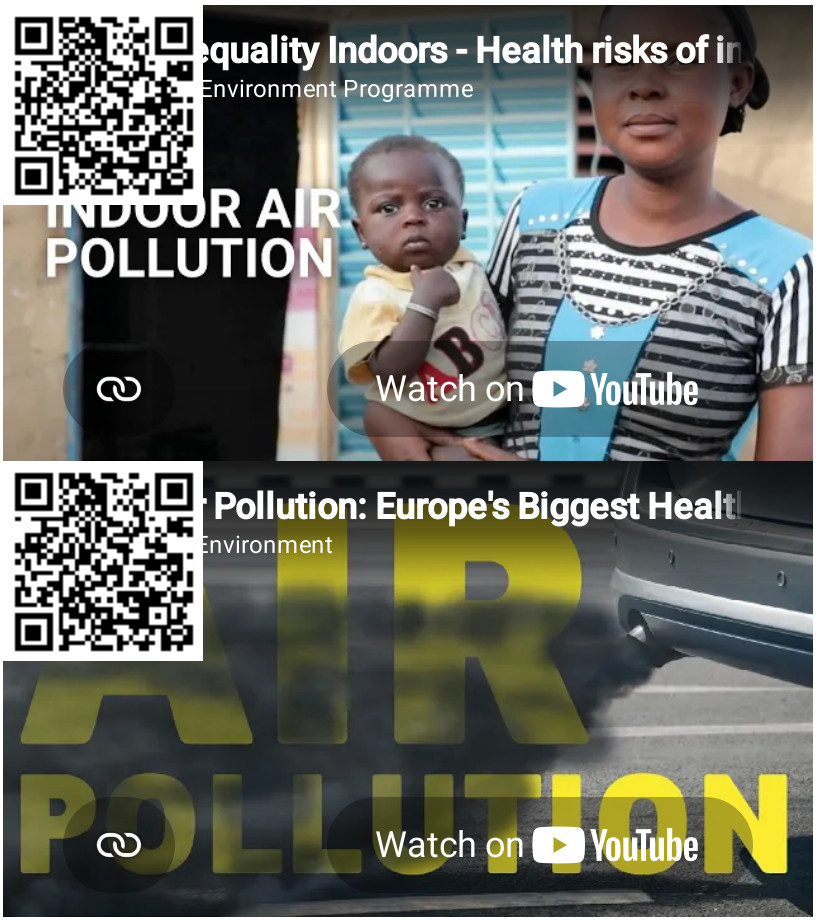
Secondhand Smoke (Environmental Tobacco Smoke)

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



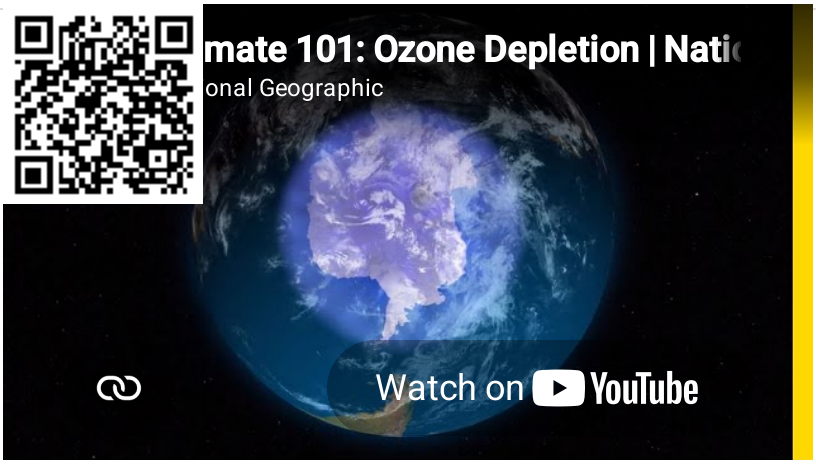
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11.2: Ozone Depletion



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.

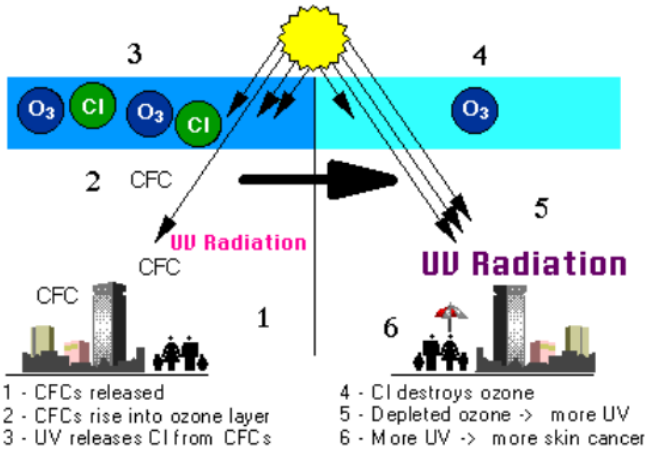


Figure 11.2.1. Strong UV light breaks apart the ODS molecule. CFCs, HCFCs, carbon tetrachloride, methyl chloroform, and other gases release chlorine atoms, and halons and methyl bromide release bromine atoms. It is these atoms that actually destroy ozone, not the intact ODS molecule. It is estimated 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 11.2.1. 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.

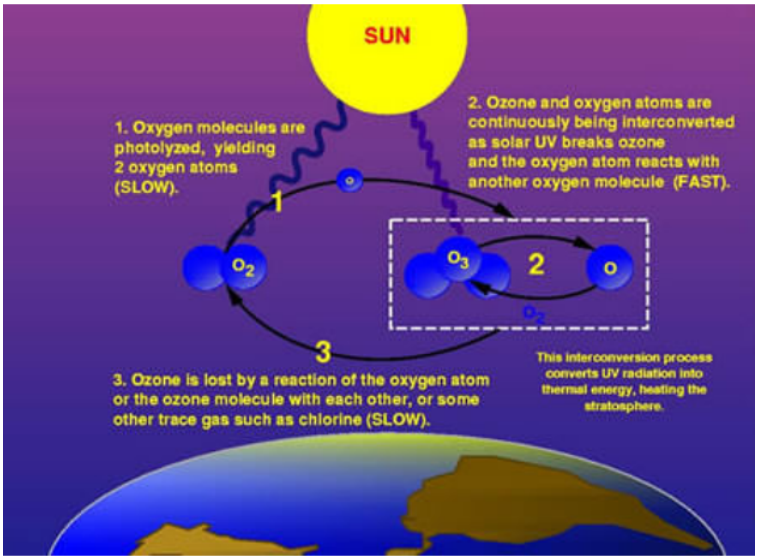


Figure 11.2.2. Because ozone filters out harmful UVB radiation, less ozone means higher UVB levels at the surface. The more the depletion, the larger the increase in incoming UVB. UVB has been linked to skin cancer, cataracts, damage to materials like plastics, and harm to certain crops and marine organisms. 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 11.2.3). 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.

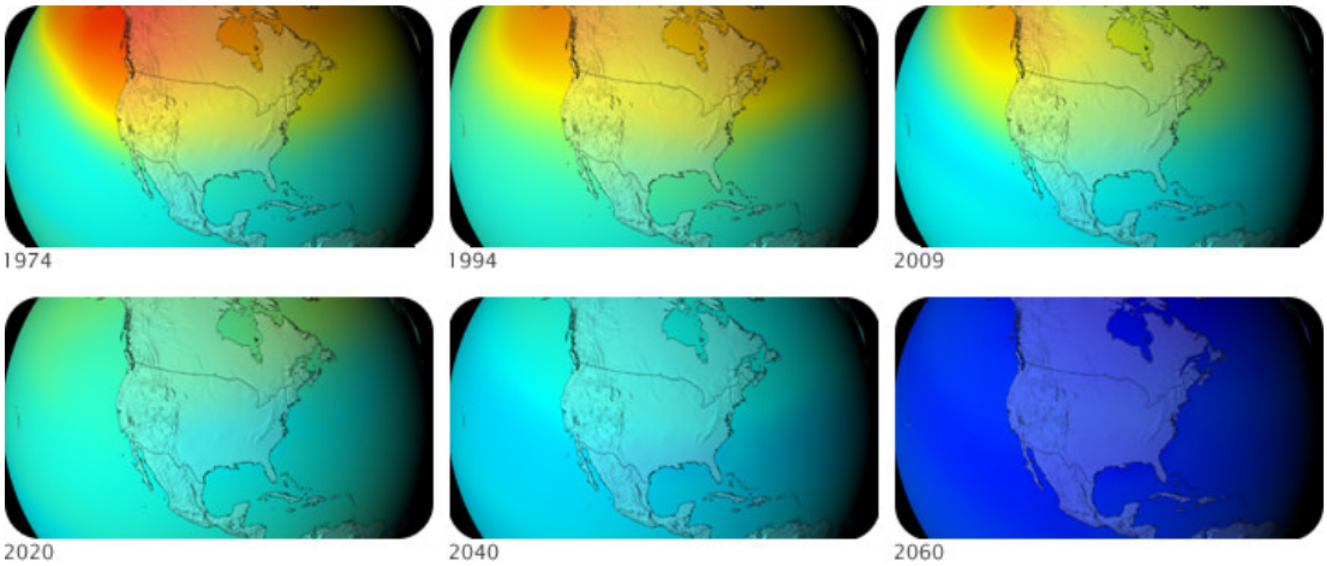
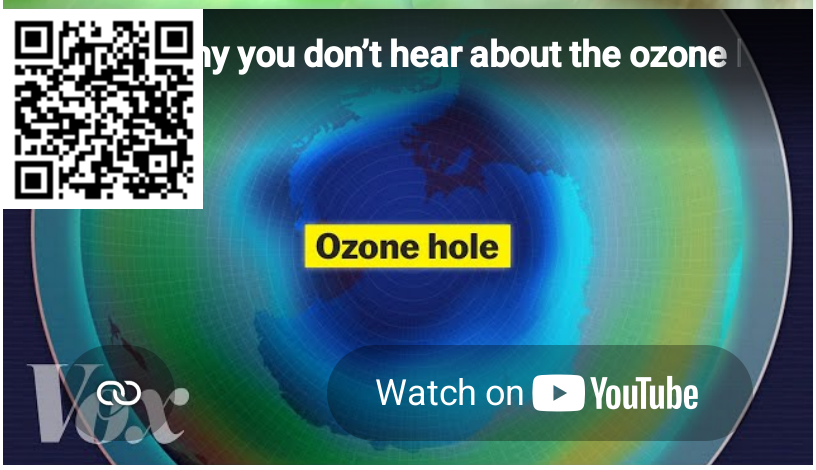


Figure 11.2.3. Ozone levels over North America decreased between 1974 and 2009. Models of the future predict what ozone levels would have been if CFCs were not being phased out. Warmer colors indicate more ozone.

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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11.3: 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.

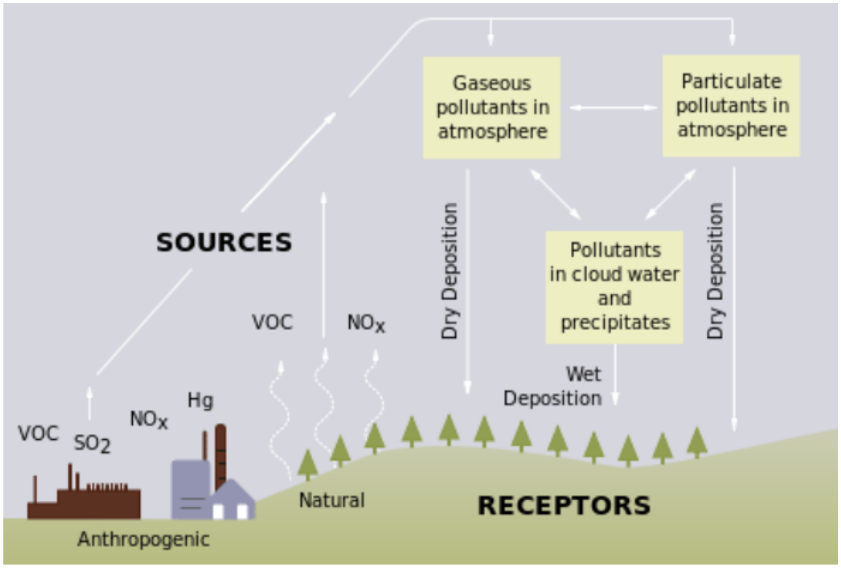
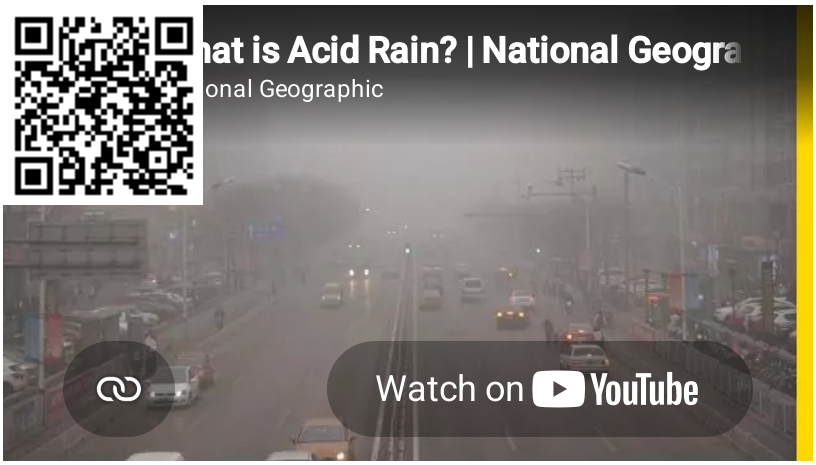


Figure 11.3.1. Processes involved in acid deposition.

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 11.3.2. 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 11.3.2).

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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11.4: Revisiting 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 11.4.1). 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.

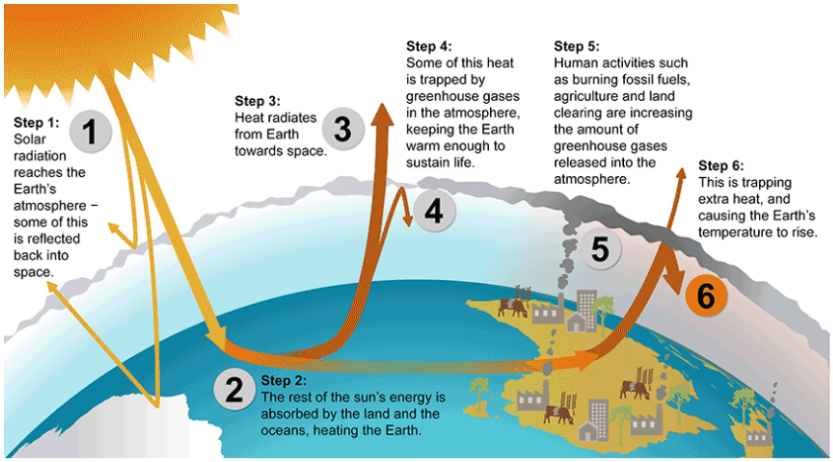


Figure 11.4.1. Enhanced Greenhouse Effect

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.

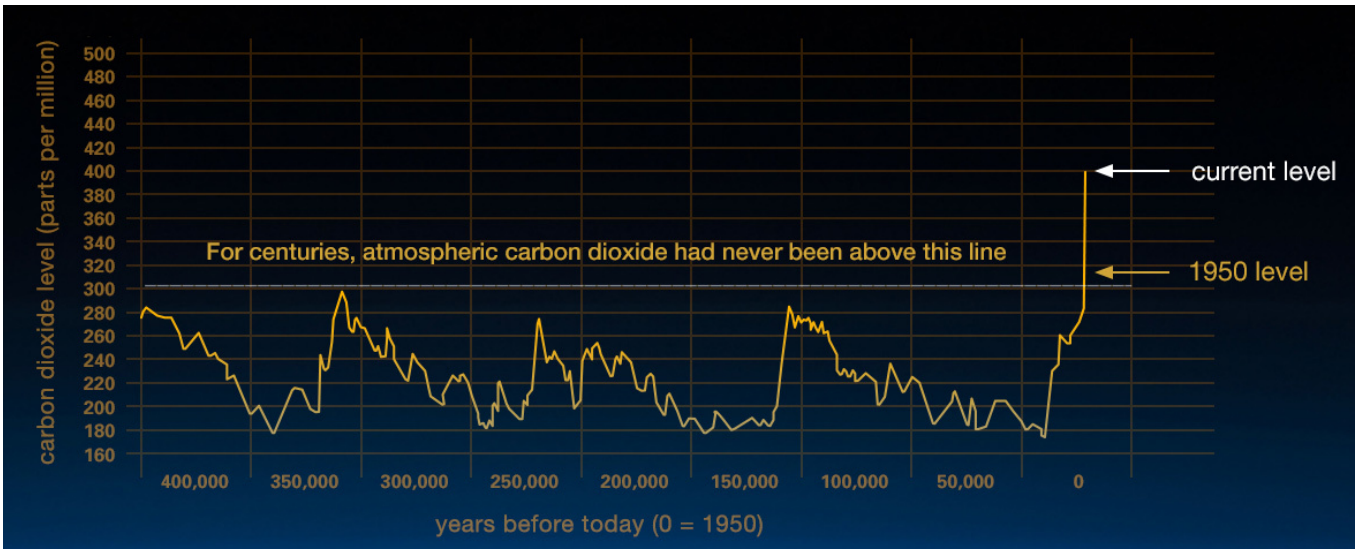


Figure 11.4.2. This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record.)

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.

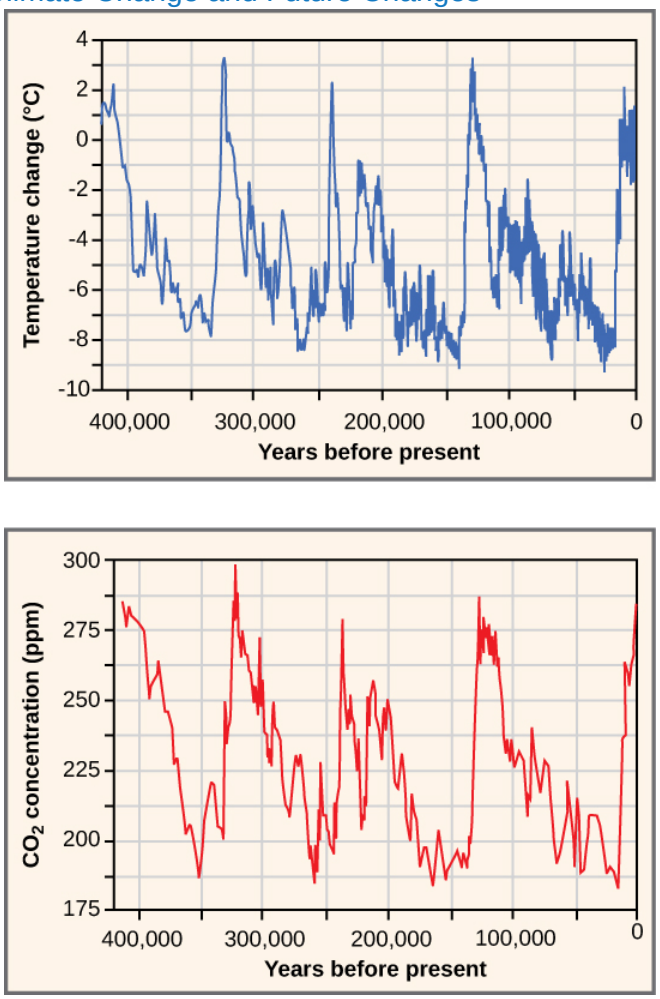


Figure 11.4.3. Ice at the Russian Vostok station in East Antarctica was laid down over the course 420,000 years and reached a depth of over 3,000 m. By measuring the amount of CO_2 trapped in the ice, scientists have determined past atmospheric CO_2 concentrations. Temperatures relative to modern day 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).

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 the process 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. <<a href="http://www.ipcc.ch/pdf/assessment-re..._SPM_FINAL.pdf" rel="freelink" title="http://www.ipcc.ch/pdf/assessment-re..._SPM_FINAL.pdf">http://www.ipcc.ch/pdf/assessment-re..._SPM_FINAL.pdf>

NASA. 2018. Global Climate Change: Vital Signs of the Planet. Website. <<a href="https://climate.nasa.gov/" rel="freelink" title="https://climate.nasa.gov/">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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11.5: 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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EPA. (n.d.). *Climate change*. Accessed August 31, 2015 at http://www.epa.gov/climatechange/. Modified from original.

University of California College Prep. (2012). *AP environmental science*. Retrieved from http://cnx.org/content/col10548/1.2/. Available under Creative Commons Attribution 4.0 International License. (CC BY 4.0). Modified from original.

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CHAPTER OVERVIEW

10: Minerals and 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

10.1: Mineral Resources and Extraction

10.2: Forms of Energy

10.3: Challenges and Impacts of Energy Use

10.4: Non-Renewable Energy Sources

10.5: Renewable Energy Sources

10.S: Chapter Resources

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10.1: Mineral Resources and Extraction



Resources

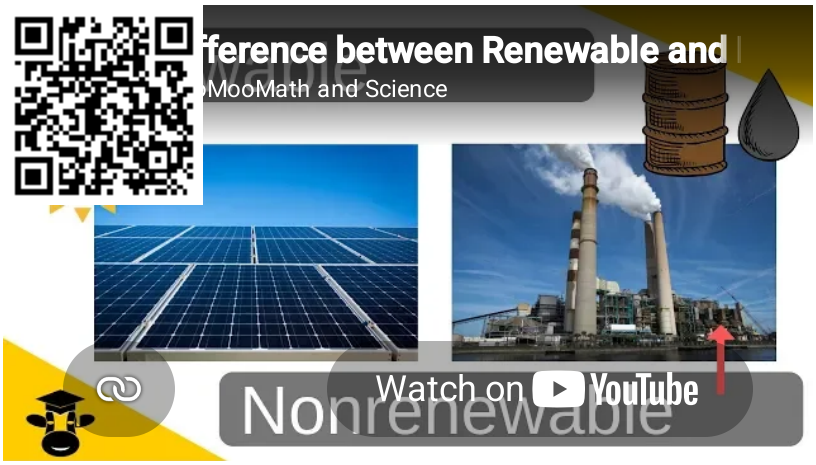
A resource is anything that can be useful, which covers quite a bit. In geology, we generally refer to things that can be *commercially* useful as resources, but not all resources are necessarily converted to money.



Resources can be classified as one of three types.

Three Types of Resources:

- **Renewable**: resources that can be remade, regrown, refreshed, or regenerated within a reasonable human timespan. The keyword in the definition is "can". Because a resources is renewable doesn't mean it will be renewed, just that given the right conditions it is possible. Examples of renewable resources are food products and the plants, animals, fungi, and protists they come from in addition to other products.
- **Non-Renewable**: resources that take a long time to form and also may only form under only special conditions - more than what is possible or practical for humans to wait for. Anything that cannot be renewed within a reasonable human timespan is considered non-renewable. Examples include all fossil fuels, minerals, and ore.
- **Perpetual**: gray area between renewable and non-renewable. Something that is in either infinite supply (for human purposes) like sunlight and wind, or which contains a supply that, even if it is technically non-renewable, it can be considered as such for humans, such as water.



Mineral Resources

Minerals are inorganic compounds and elements with a regular crystalline structure found in the earth's crust that can be used for a variety of purposes. Resources can often be obtained from minerals or mineral-like matter. This can be broken down into metallic and non-metallic mineral resources. In this definition, the word mineral is used loosely - things that do not technically meet the definition of a mineral can still be thought of as a mineral resource (as mineral-like matter, like volcanic glass).



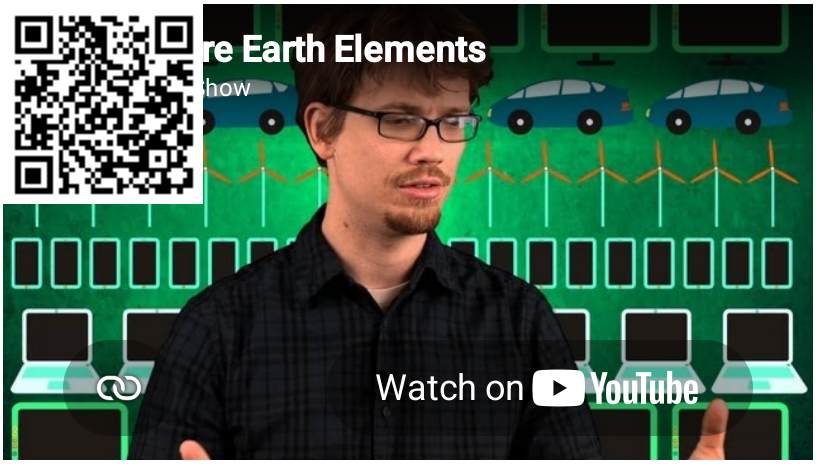
Mineral resources can be organized into four main categories:

- **Identified Resources**: Identified as having a known location, quality, and quantity.
- **Reserves**: Resources that can be used in a cost-effective manner given the current prices of the specified resource.
- **Undiscovered Reserves**: Reserves of a given resource that are believed to exist.
- **Other Resources**: Mineral resources that have not yet been discovered or identified resources that are not considered to be reserves.

All minerals that are valuable to humans and, therefore, economically desirable for extraction are collectively called ore minerals.

Some common and important ores include:

Ore	Metal/Use
Argentite	Silver
Barite	Barium
Bauxite	Aluminum
Beryl	Gemstones
Bornite	Copper
Cassiterite	Tin
Chalcocite	Copper
Chromite	Chromium
Cinnabar	Mercury
Cobaltite	Cobalt
Galena	Lead
Gold	Gold
Hematite	Iron
Ilmenite	Titanium
Magnetite	Iron
Molybdenite	Molybdenum
Sphalerite	Zinc
Uraninite	Uranium
Wolframite	Tungsten



Non-Metallic Mineral Resources

Not all mineral resources are used to obtain metals. Some resources produce non-metallic items that can be used commercially. This includes many resources that become building materials.

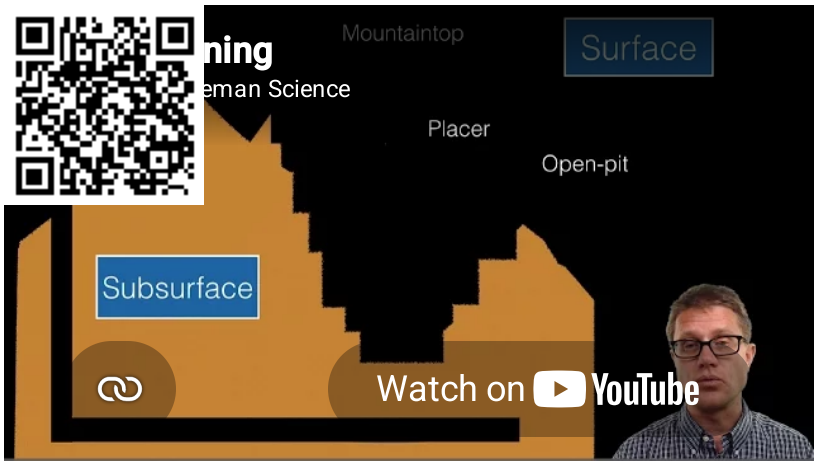
Resource	Use
Rock Salt	Food additive, aquarium supplies, snow/ice melt
Sand	Concrete, building materials, playgrounds, beach replenishment, glassmaking
Clay	Building materials, ceramics, art supply, pottery
Gypsum	Building materials (drywall)
Limestone	Road base, building materials, lime, cement

Formation of Mineral Deposits

Minerals can be formed through a variety of processes. See Section 3.1 of this text for a review.

Extraction of Mineral Deposits

Ores are not useful, generally, by themselves. They must be mined - removed from their native surroundings using tools or machinery. Although in ancient times, mining was performed with simple tools, modern mining requires extensive amounts of heavy machinery. A location where mining occurs is a mine, although mines may be used to obtain resources other than ores or mineral resources (coal, for example, is mined).



There are several common types of modern mining:

Subsurface mining

Sometimes, mineral resources are far below the surface of the earth. In these cases, **subsurface mining** must be used, which causes less environmental damage but is more expensive and also more dangerous for miners due to fires, explosions, and cave-ins. In the early years of coal mining (1880-1910), there was an average of 1,500 deaths or more per year. 1907 was the deadliest year in U.S. coal mining history, with a total of 3,242 deaths. Over the years, conditions have thankfully improved, and the death toll of miners has decreased to an average of less than 35 people a year in the US, although it is much higher in many other parts of the world.

Subsurface mining is the digging of tunnels or shafts into the ground to obtain ores or other useful deposits and includes:

- Shaft mining - vertical shafts dug into the earth
- Drift mining - horizontal shafts dug into the earth
- Slope mining - diagonal shafts dug into the earth
- Room and pillar - cutting networks of open areas (rooms) into horizontal layers with pillars left for structural stability. The most popular method for subsurface mining.
- Solution/in-situ leach mining - hot water is forced into mineral ore, followed by compressed air, causing the solution of water and dissolved minerals to rise to the surface

Surface mining

In **surface mining,** extraction occurs when **overburden** (layers of rock and soil on top of a mineral resource) is removed and discarded as a waste product. Surface mining causes many extensive environmental problems, including air and soil pollution. **Leachate**, the contaminated water left over from surface mining, is of particular concern and leads to both surface and groundwater contamination.

The Surface Mining Control and Reclamation Act of 1977 was passed by the U.S. government in an attempt to lessen mining's environmental impact. This Act requires mining companies to **reclaim** or restore most surface-mined land. However, many mining companies have found loopholes to avoid following this law.



Approximately 90% of non-fuel mineral resources and 60% of coal are extracted in the United States using surface mining.

Techniques include:

- Open-pit mining - removal of material through an open hole in the surface, usually quite wide.
- Strip mining - removal of surface materials to allow access to shallow materials underneath.
- Mountaintop removal - literal removal of a mountaintop to expose materials, common in coal mining.

Mountaintop mining (MTM), while less hazardous to workers, has particularly detrimental effects on land resources. Companies use MTM to expose mineral and coal seams from the tops of mountains, destroying all vegetation and topsoil and disposing of the associated mining waste in adjacent valleys, which buries streams and other important habitats.



Figure 10.1.2. Mountaintop Removal Coal Mining in Martin County, Kentucky Photograph shows mountaintop coal removal mining in Martin County, Kentucky. Source: Flashdark.

Processing

Mining alone is usually not enough to make use of most ores or other mineral resources. These ores and other resources generally must be processed before their final use. Bauxite, for example, contains aluminum, which may eventually be useful. However,

bauxite is not pure, and even bauxite, which is closer to purity, must have the bauxite separated from other nearby minerals that may have been attached, then the aluminum must be removed from the bauxite.

Smelting is the process of melting a metal out of mineral ore.

Tailings are the remnants left over from the ore after the metals have been removed. They are not generally useful, and their disposal presents environmental and health concerns.

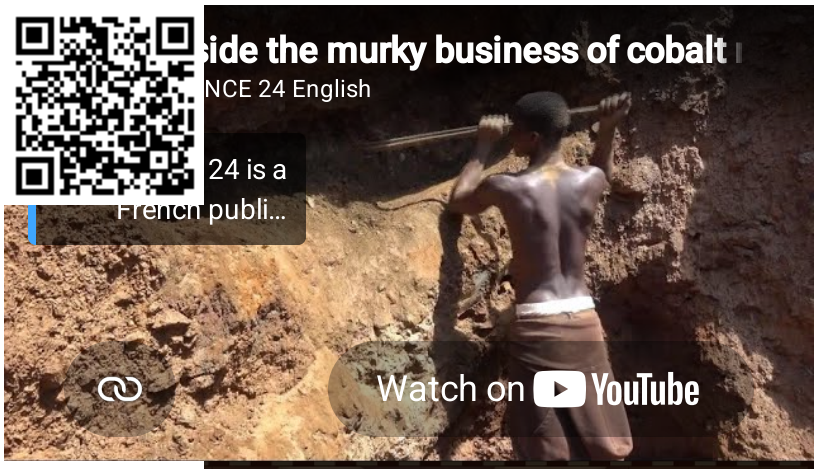


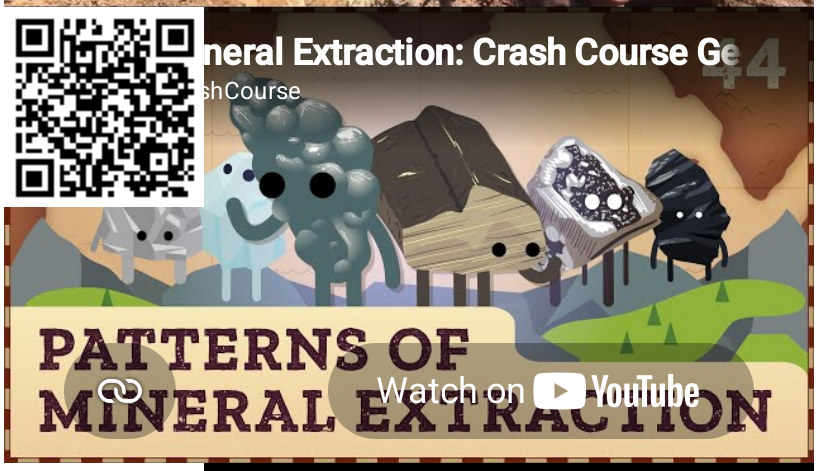
The Global Economics and Impacts of Mining

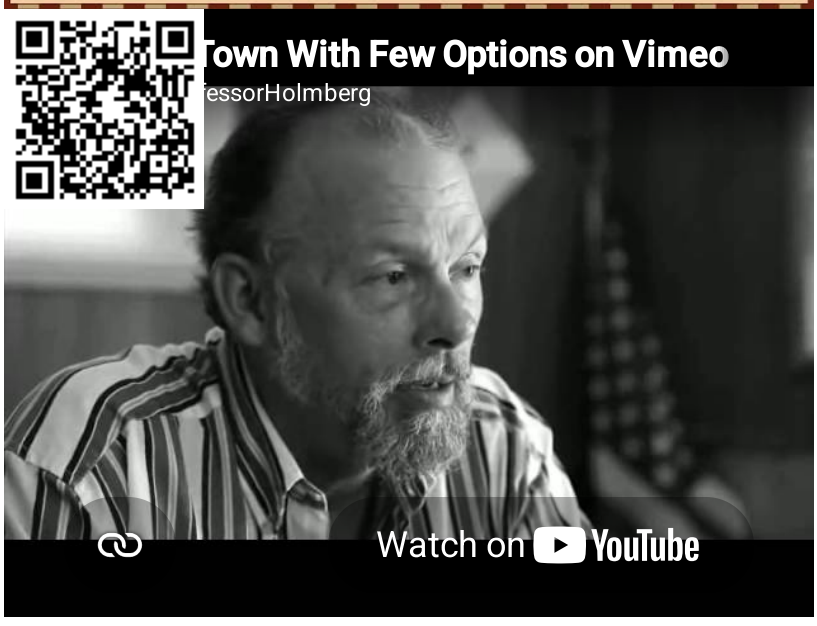
The economics of mining are such that, in many communities and parts of the world, entire economies are based on the extraction of minerals and fossil fuels, most of which are not meant to be used locally. The companies employing locals are most often multinational corporations working through a series of subsidiaries. There is also a modern-day land rush by companies and governments for minerals and fuels in areas of the world that have not yet been mined, such as in sub-Saharan Africa, parts of Asia, and South America.

In addition to the many environmental issues, this is difficult for the local populations, who do not have many alternatives for making an income. Once the seams are tapped out or the mines are no longer economically viable, the companies claim bankruptcy or vacate, leaving the local communities to try to diversify their economy once more and find a way to live with what is left of their environment.









Primary Solutions

The 5 Rs, in order of effectiveness:

- Refusing resources (most effective)
- Reducing resources
- Repurposing resources
- Reusing resources

- Recycling resources (least effective)



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10.2: Forms of Energy



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INTRODUCTION

Energy is the ability to do **work**. Work is done when a force is applied to an object over a distance. Any moving object has **kinetic energy** or energy of motion, and it thus can do work. Similarly, work has to be done on an object to change its kinetic energy. The kinetic energy of an object of mass m and speed v is given by the relation

$$E = \frac{1}{2}mv^2. \tag{10.2.1}$$

Sometimes energy can be stored and used at a later time. For example, a compressed spring and water held back by a dam both have the potential to do work. They are said to possess **potential energy**. When the spring or water is released its potential energy is transformed into kinetic energy and other forms of energy such as heat. The energy associated to the gravitational force near the surface of the earth is potential energy. Other forms of energy are really combinations of kinetic and potential energy. Chemical energy, for example, is the electrical potential energy stored in atoms. Heat energy is a combination of the potential and kinetic energy of the particles in a substance.

FORMS OF ENERGY

Mechanical energy puts something in motion. It moves cars and lifts elevators. A machine uses mechanical energy to do work. The mechanical energy of a system is the sum of its kinetic and potential energy. Levers, which need a fulcrum to operate, are the simplest type of machine. Wheels, pulleys and inclined planes are the basic elements of most machines.

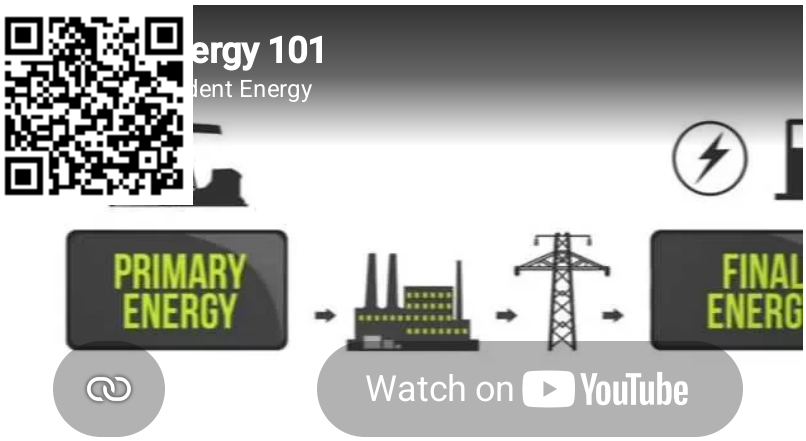
Chemical energy is the energy stored in molecules and chemical compounds, and is found in food, wood, coal, petroleum and other fuels. When the chemical bonds are broken, either by combustion or other chemical reactions, the stored chemical energy is released in the form of heat or light. For example, muscle cells contain glycogen. When the muscle does work the glycogen is broken down into glucose. When the chemical energy in the glucose is transferred to the muscle fibers some of the energy goes into the surroundings as heat.

Electrical energy is produced when unbalanced forces between electrons and protons in atoms create moving electrons called electric currents. For example, when we spin a copper wire through the poles of a magnet we induce the motion of electrons in the wire and produce electricity. Electricity can be used to perform work such as lighting a bulb, heating a cooking element on a stove or powering a motor. Note that electricity is a "secondary" source of energy. That means other sources of energy are needed to produce electricity.

Radiant energy is carried by waves. Changes in the internal energy of particles cause the atoms to emit energy in the form of electromagnetic radiation which includes visible light, ultraviolet (UV) radiation, infrared (IR) radiation, microwaves, radio waves, gamma rays, and X-rays. Electromagnetic radiation from the sun, particularly light, is of utmost importance in environmental systems because biogeochemical cycles and virtually all other processes on earth are driven by them.

Thermal energy or **Heat energy** is related to the motion or vibration of molecules in a substance. When a thermal system changes, heat flows in or out of the system. Heat energy flows from hot bodies to cold ones. Heat flow, like work, is an energy transfer. When heat flows into a substance it may increase the kinetic energy of the particles and thus elevate its temperature. Heat flow may also change the arrangement of the particles making up a substance by increasing their potential energy. This is what happens to water when it reaches a temperature of 100ºC. The molecules of water move further away from each other, thereby changing the state of the water from a liquid to a gas. During the phase transition the temperature of the water does not change.

Nuclear Energy is energy that comes from the binding of the protons and neutrons that make up the nucleus of the atoms. It can be released from atoms in two different ways: nuclear fusion or nuclear fission. In **nuclear fusion**, energy is released when atoms are combined or fused together. This is how the sun produces energy. In **nuclear fission**, energy is released when atoms are split apart. Nuclear fission is used in nuclear power plants to produce electricity. Uranium 235 is the fuel used in most nuclear power plants because it undergoes a chain reaction extremely rapidly, resulting in the fission of trillions of atoms within a fraction of a second.



SOURCES AND SINKS

The source of energy for many processes occurring on the earth's surface comes from the sun. Radiating solar energy heats the earth unevenly, creating air movements in the atmosphere. Therefore, the sun drives the winds, ocean currents and the water cycle. Sunlight energy is used by plants to create chemical energy through a process called photosynthesis, and this supports the life and growth of plants. In addition, dead plant material decays, and over millions of years is converted into fossil fuels (oil, coal, etc.).

Today, we make use of various sources of energy found on earth to produce electricity. Using machines, we convert the energies of wind, biomass, fossil fuels, water, heat trapped in the earth (geothermal), nuclear and solar energy into usable electricity. The above sources of energy differ in amount, availability, time required for their formation and usefulness. For example, the energy released by one gram of uranium during nuclear fission is much larger than that produced during the combustion of an equal mass of coal.

Table: US ENERGY PRODUCTION (Quadrillion BTU)

(Source: US DOE)	1975	2020
Coal	14.989 (24.4%)	9.2 (10%)
Natural Gas (dry)	21.9 (35.9%)	31.5 (34%)
Crude Oil	17.729 (28.9%)	32.2 (35%)
Nuclear	1.900 (3.1%)	8.2 (9%)
Renewable	4.55 (7.6%)	11.6 (12%)
TOTAL	61.356	92.7

(Source: US Department of Energy)

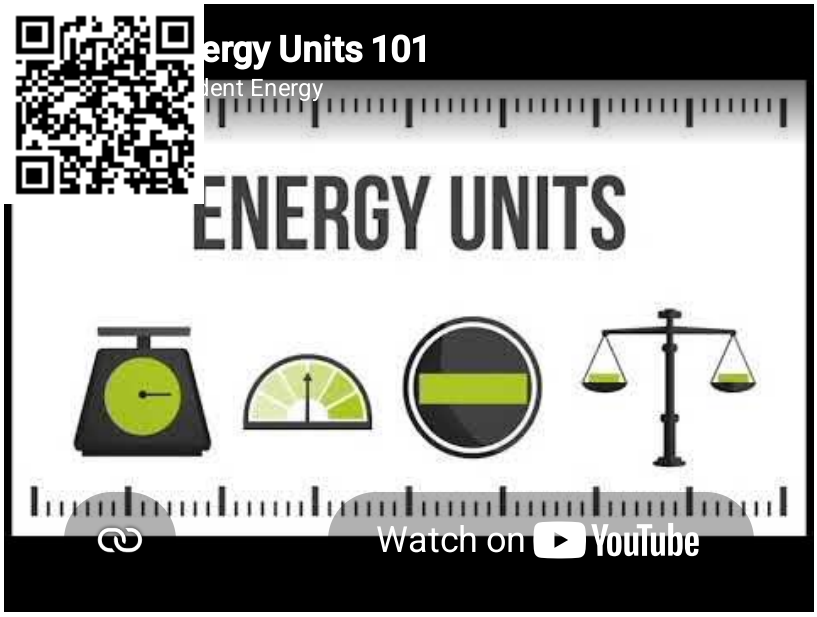
An **energy sink** is anything that collects a significant quantity of energy that is either lost or not considered transferable in the system under study. Sources and sinks have to be included in an energy budget when accounting for the energy flowing into and out of a system.

CONSERVATION OF ENERGY

Though energy can be converted from one form to another, energy cannot be created or destroyed. This principle is called the "law of conservation of energy." For example, in a motorcycle, the chemical potential energy of the fuel changes to kinetic energy. In a radio, electricity is converted into kinetic energy and wave energy (sound).

Machines can be used to convert energy from one form to another. Though ideal machines conserve the mechanical energy of a system, some of the energy always turns into heat when using a machine. For example, heat generated by friction is hard to collect and transform into another form of energy. In this situation, heat energy is usually considered unusable or lost.

ENERGY UNITS



Electrical energy is generally expressed in **kilowatt-hours** (kWh):

1 kilowatt−hour=3,600,000 Joules

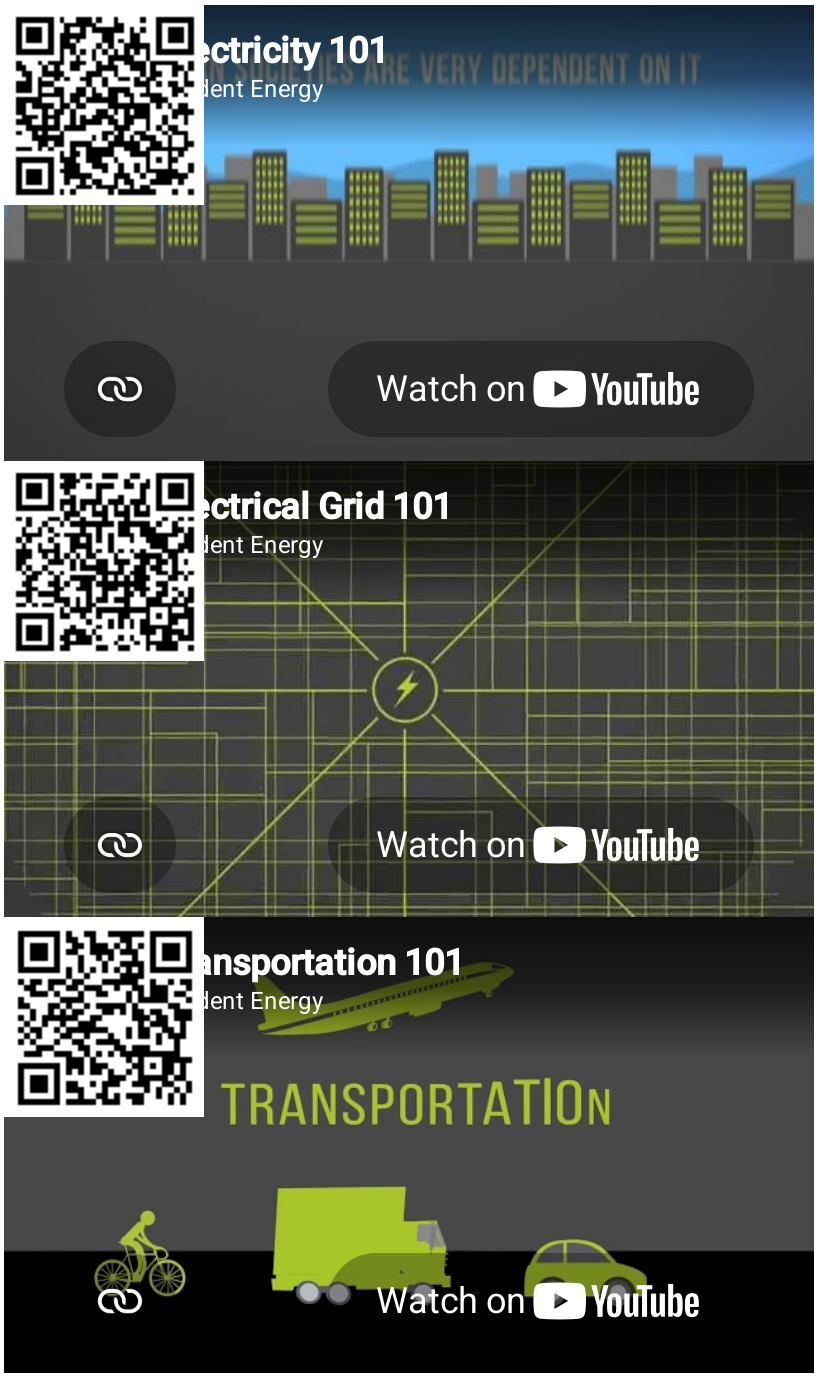
It is important to realize that a kilowatt-hour is a unit of energy not power. For example, an iron rated at 2000 Watts would consume 2x3.6x106J of energy in 1 hour.

Heat energy is often measured in calories. One calorie (cal) is defined as the heat required to raise the temperature of 1 gram of water from 14.5 to 15.5 ºC:

1 calorie=4.189 Joules

An old, but still used unit of heat is the **British Thermal Unit** (BTU).

“1 BTU=1055 Joules”



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10.3: 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 10.3.2).

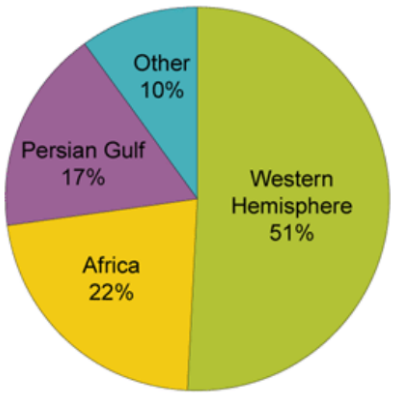


Figure illustrates that the United States imported over half of the crude oil and refined petroleum products that it consumed during 2009. Source: U.S. Energy Information Administration, Petroleum Supply Annual, 2009, preliminary data.

The major holder of oil reserves is the **Organization of Petroleum Exporting Countries,** (OPEC) (Figure 10.3.3). 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.

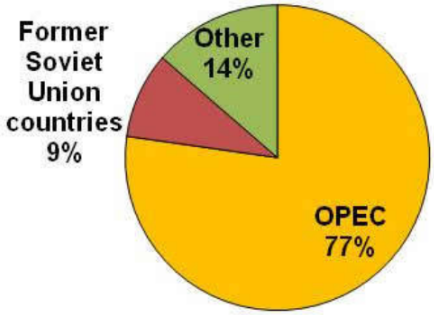


Figure 10.3.3. Proven Oil Reserves Holders Pie chart shows proven oil reserves holders. Source: C. Klein-Banai using data from BP Statistical Review of World Energy (2010)

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.

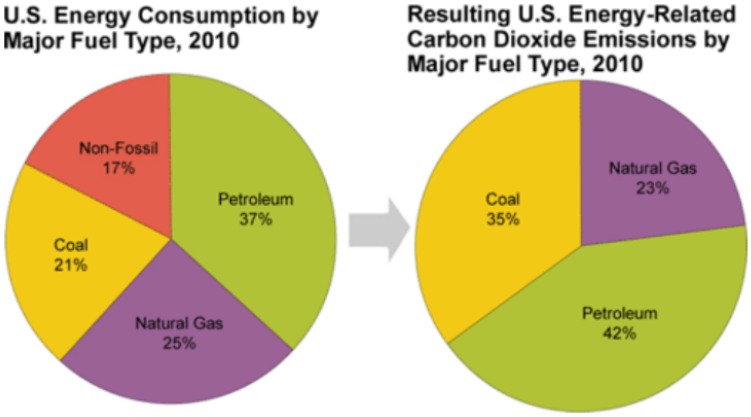


Figure 10.3.4. Fuel Type and Carbon Emissions The two charts show the relationship between fuel type and carbon emissions for U.S. energy consumption in 2010. Source: U.S. Energy Information Administration







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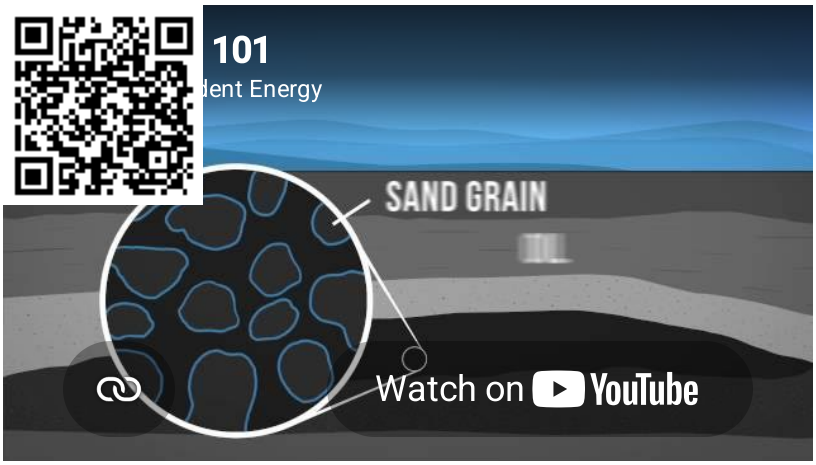
10.4: Non-Renewable Energy Sources

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.



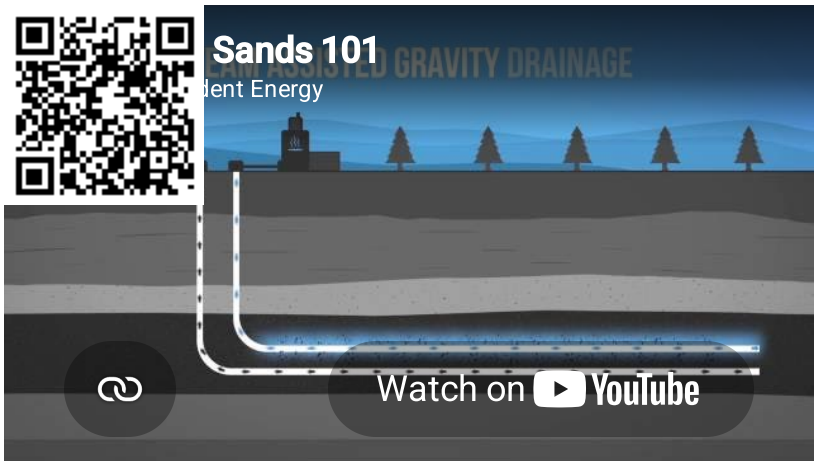
Environmental Impacts of Oil Extraction and Refining

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.

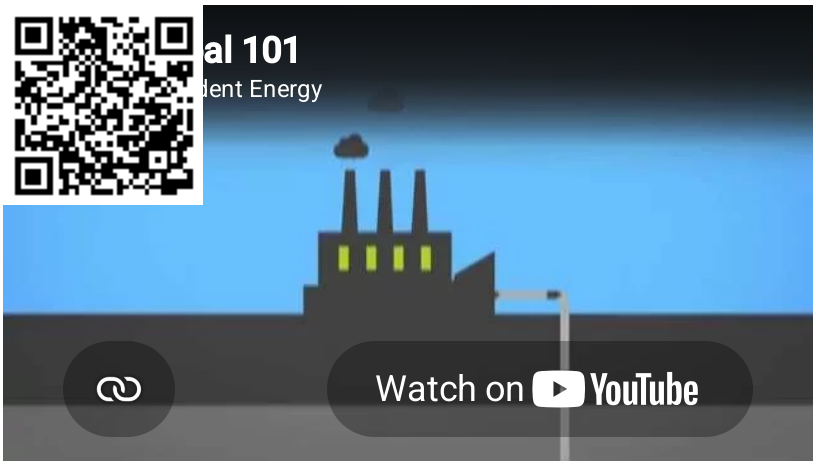
Coal



Figure 10.4.1. 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 10.4.1). 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.



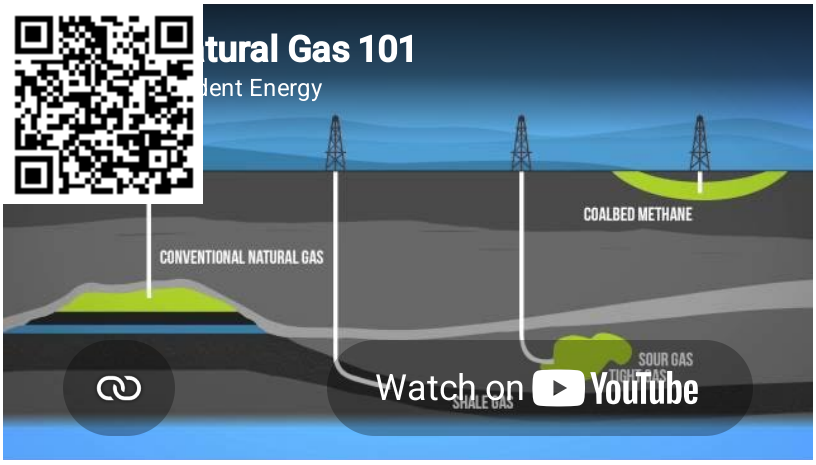
Coal is plentiful and inexpensive, when looking only at the market cost relative to the cost of other sources of electricity, but its extraction, transportation, and use produces a multitude of environmental impacts that the market cost does not truly represent.

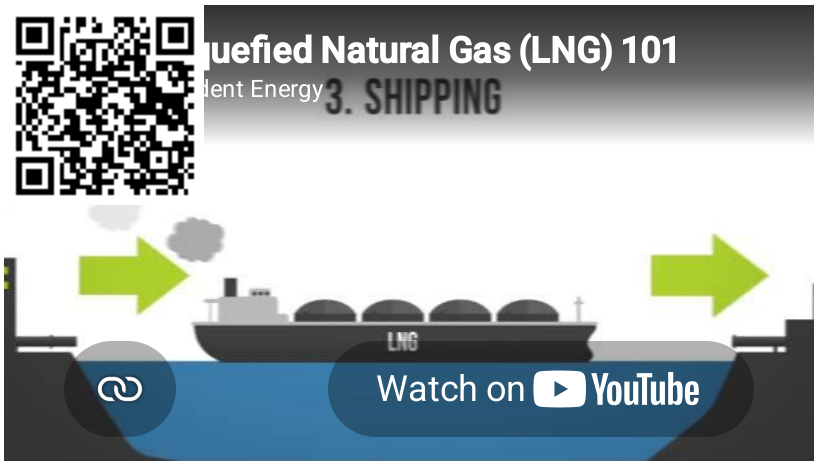
Mining and burning coal can have many detrimental effects on the environment, in addition to their toll on human lives. Burning coal emits sulfur dioxide, nitrogen oxide, and mercury, which have been linked to acid rain, smog, and health issues. In addition, burning coal currently contributes to 35% of the annual global CO_2 emissions for the US. This makes this mineral resource a major contributor to the enhanced greenhouse effect that is causing global climate change. Ash generated from combustion contributes to water contamination. As noted in Section 10.1, most 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. There is also a 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.

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 10.4.3 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).

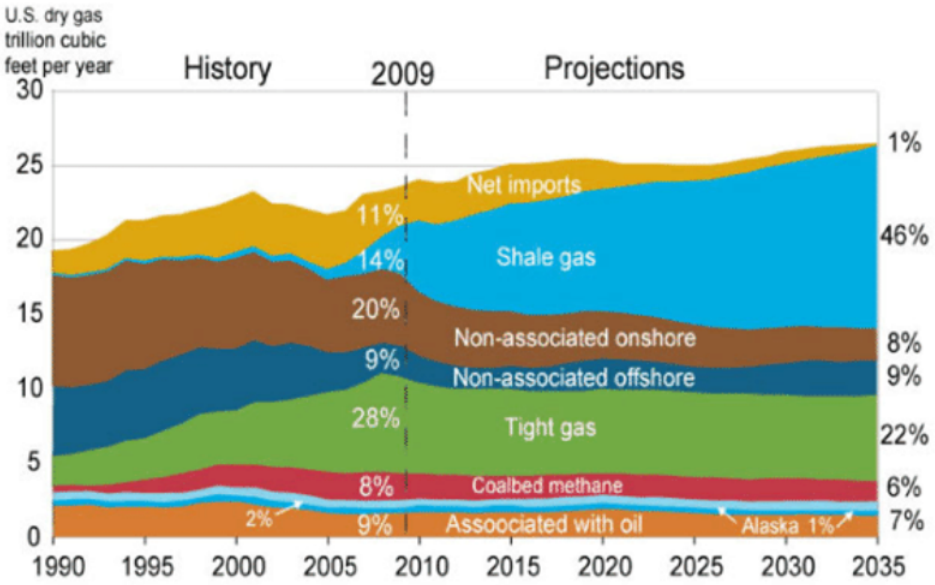
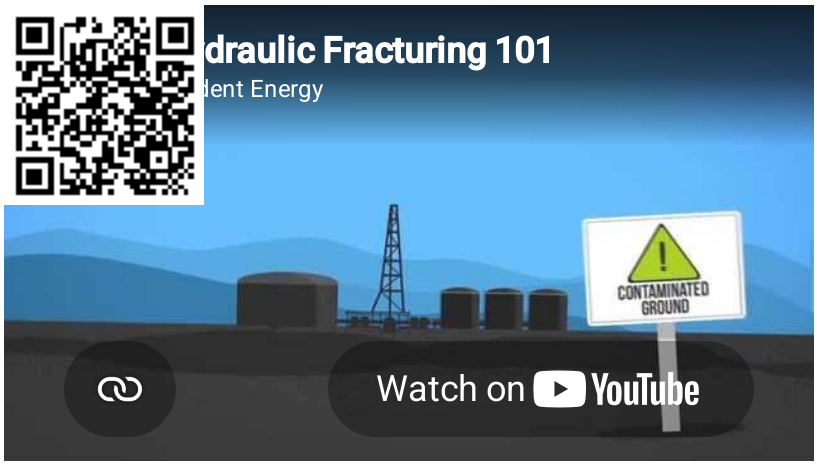


Figure 10.4.3. U.S. Natural Gas Supply, 1990-2035 Graph shows U.S. historic and projected natural gas production from various sources. Source: U.S. Energy Information Administration

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 10.4.4). 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).



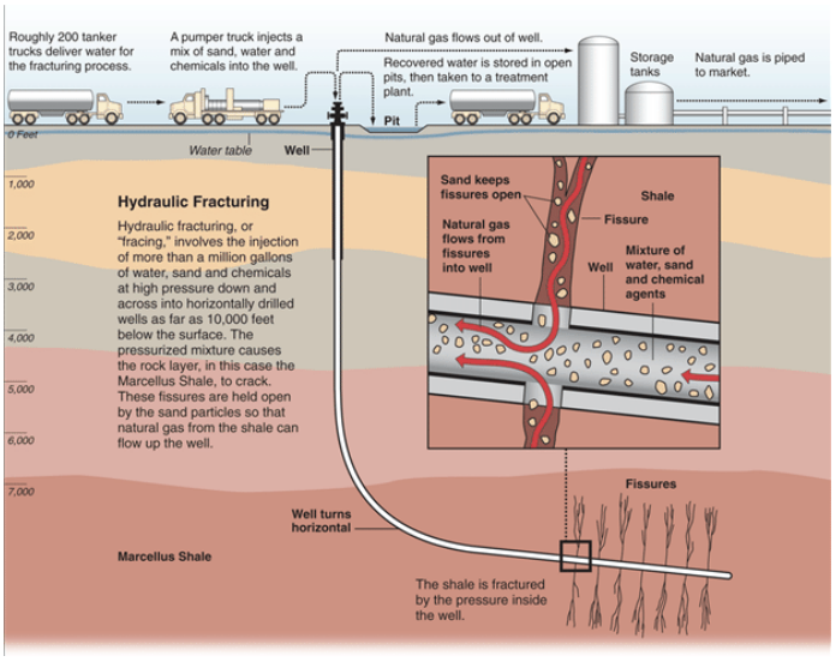


Figure 10.4.4. Graphic illustrates the process of hydraulic fracturing. Source: Al Granberg, ProPublica.

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.

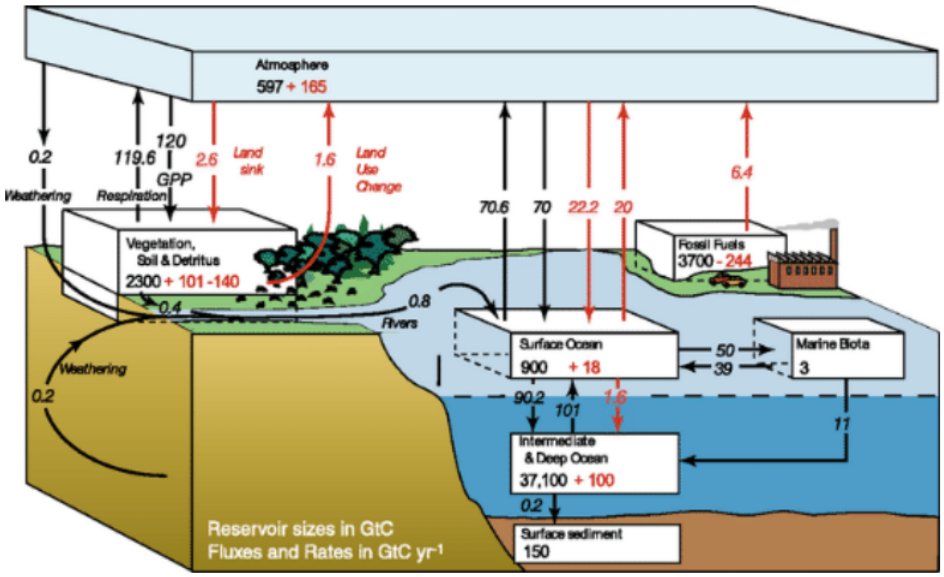
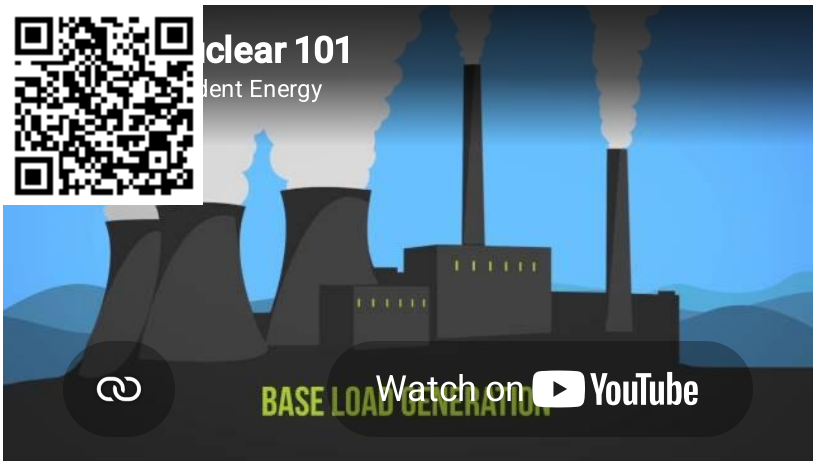


Figure 10.4.5. Global Carbon Cycle, 1990s The global carbon cycle for the 1990s, showing the main annual fluxes in GtC yr–1: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red. Source: Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth 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 10.4.7).



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.

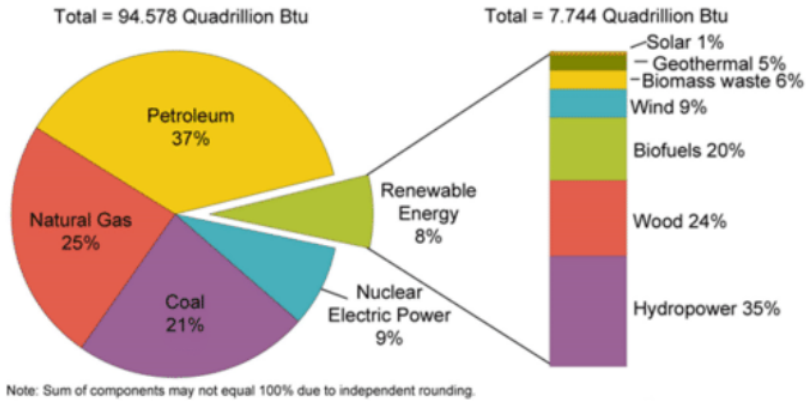


Figure 10.4.7. U.S. Energy Consumption by Energy Source, 2009 Renewable energy makes up 8% of U.S. energy consumption. Source: U.S. Energy Information Administration

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.

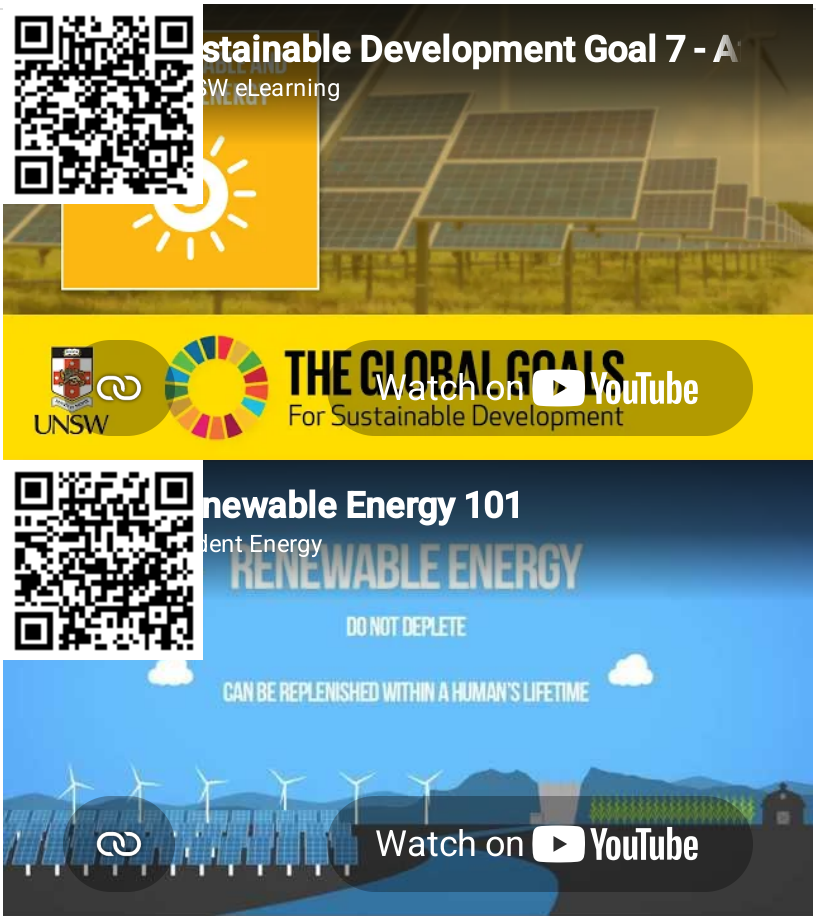
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10.5: Renewable Energy Sources



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.

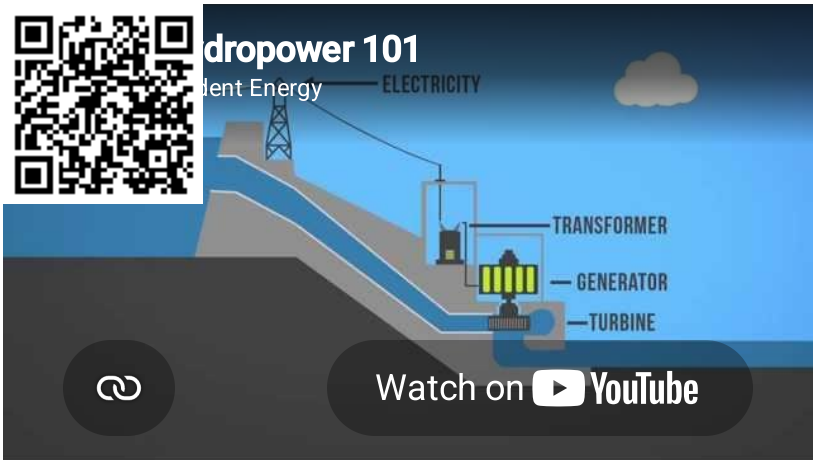




Figure 10.5.1. Hoover Power Plant View of Hoover Power Plant on the Colorado River as seen from above. Source: U.S. Department of the Interior

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

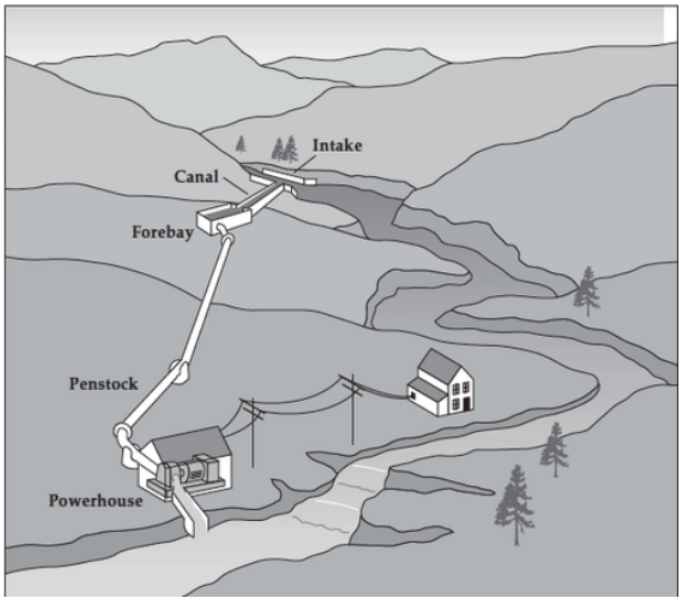


Figure 10.5.2. Microhydropower system. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, 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 10.5.2). 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

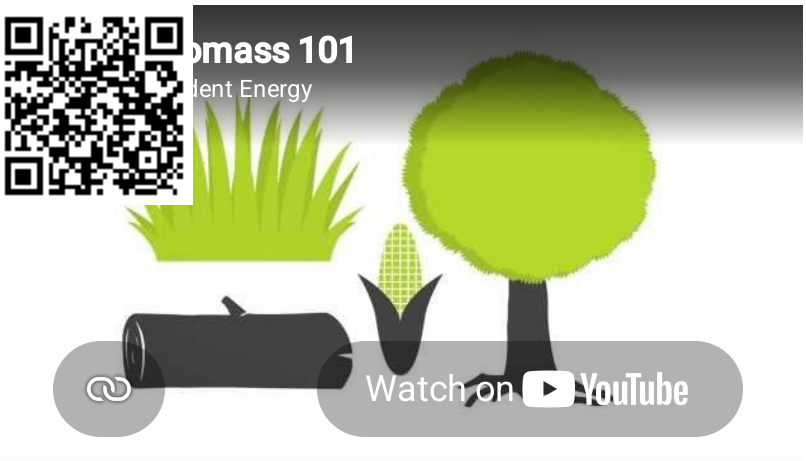
Municipal solid waste (MSW) is commonly known as garbage and can create electricity by burning it directly or by burning the methane produced as it decays. Waste to energy processes are gaining renewed interest as they can solve two problems at once: disposal of waste and production of energy from a 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

Biomass



Figure 10.5.3. 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

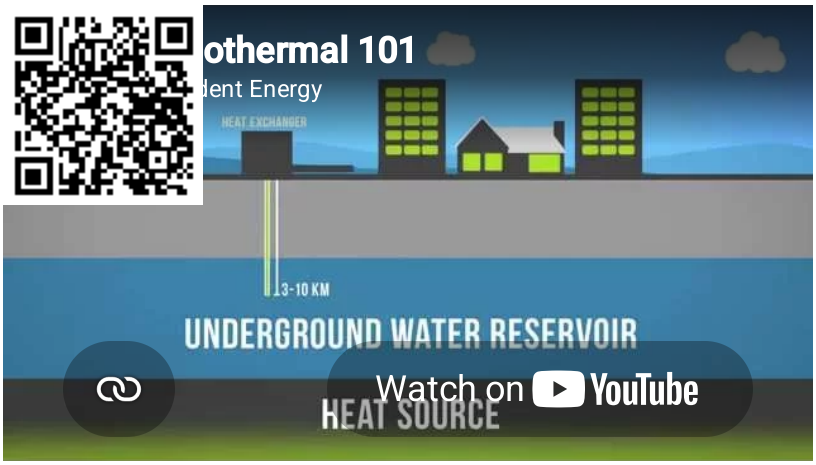
Bioethanol and **biodiesel** are liquid biofuels manufactured from plants, typically crops. Bioethanol can be easily fermented from sugar cane juice, as is done in Brazil. Bioethanol can also be fermented from broken down corn starch, as is mainly done in the United States. The economic and social effects 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.

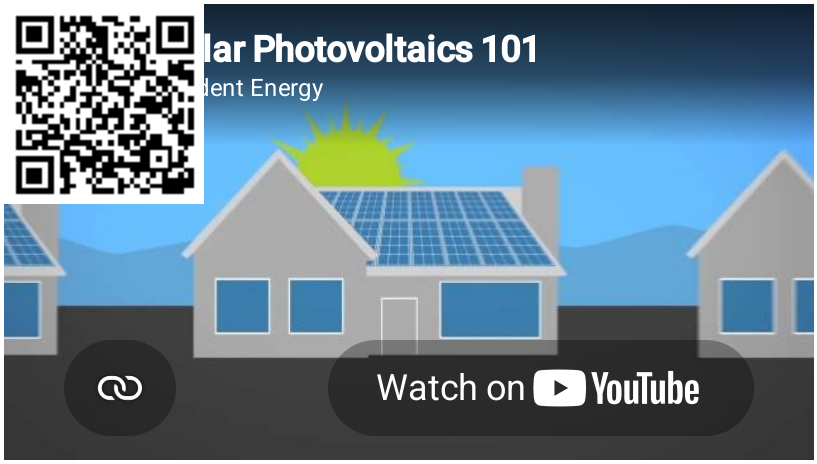


Geothermal power plants do not burn fuel to generate electricity so their emission levels are very low. They release less than 1% of the carbon dioxide emissions of a fossil fuel plant. Geothermal plants use scrubber systems to clean the air of hydrogen sulfide that is naturally found in the steam and 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.



Figure 10.5.4. 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.

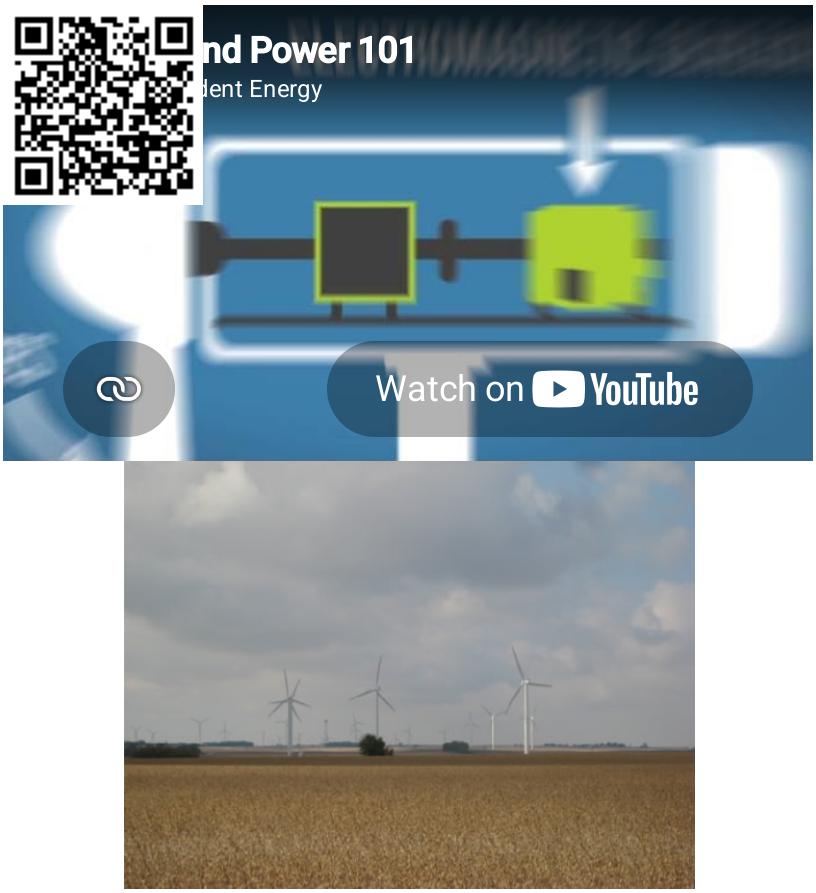
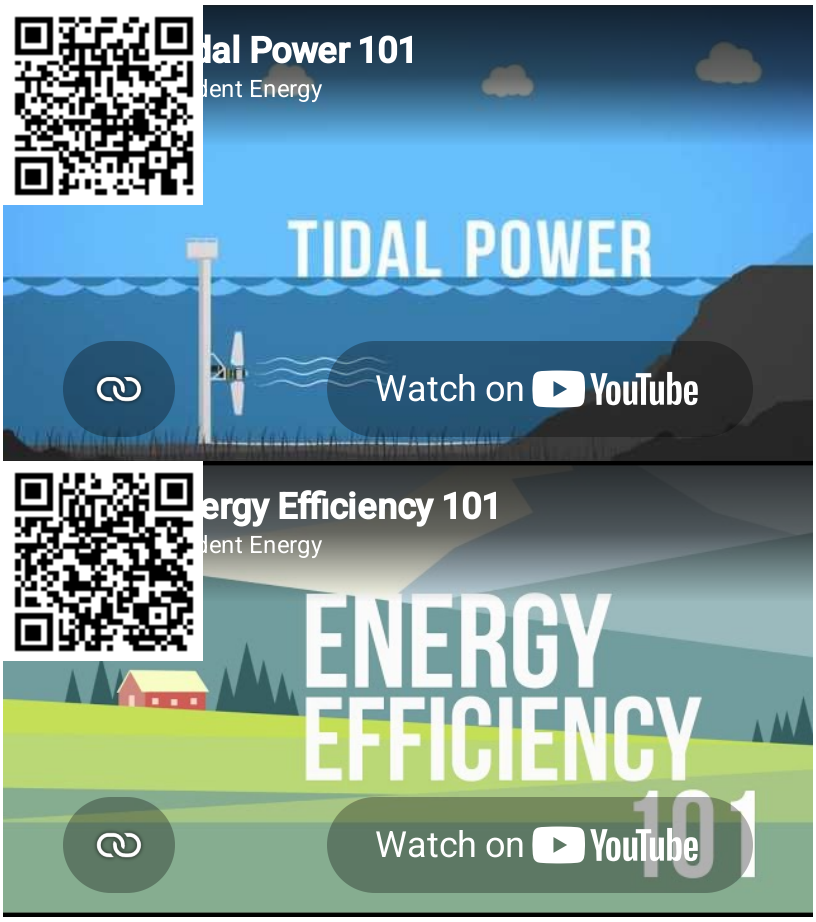


Figure 10.5.5. Twin Groves Wind Farm, Illinois Wind power is becoming a more popular source of energy in the United States. Source: Office of Sustainability, UIC

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.

Other







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.

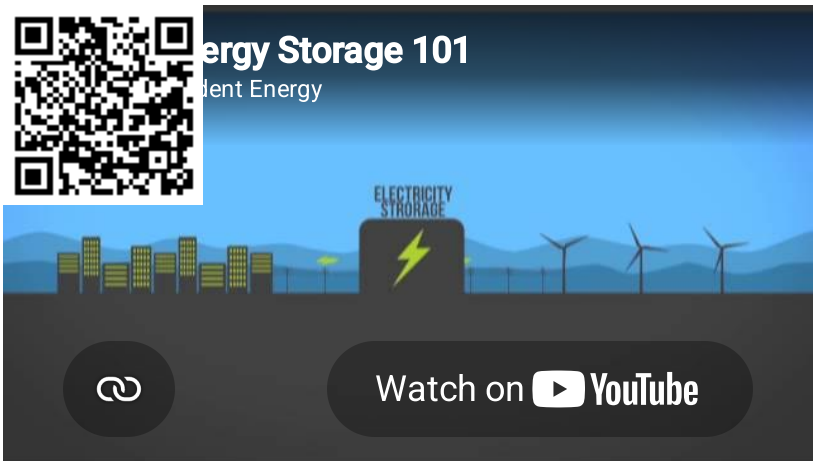
Geothermal energy originates from heat rising to the surface from earth's molten iron core created during the formation and compression of the early earth as well as from heat produced continuously by radioactive decay of uranium, thorium and potassium in the earth's crust. Tidal energy arises from the 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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10.S: 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

EEA. (2013). *Combined heat and power.* Retrieved from www.eea.europa.eu/data-and-maps/indic ators/combined-heat-and-power-chp-1. Available under Creative Commons Attribution License 3.0 (CC BY 3.0). Modified from original.

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CHAPTER OVERVIEW

12: 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

12.1: Water Cycle and Fresh Water Supply

12.2: Water Supply Problems and Solutions

12.3: Case Study - The Aral Sea - Going, Going, Gone

12.4: Water Pollution

12.5: Water Treatment

12.6: Chapter Resources

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12.1: 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 12.1.1). 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.

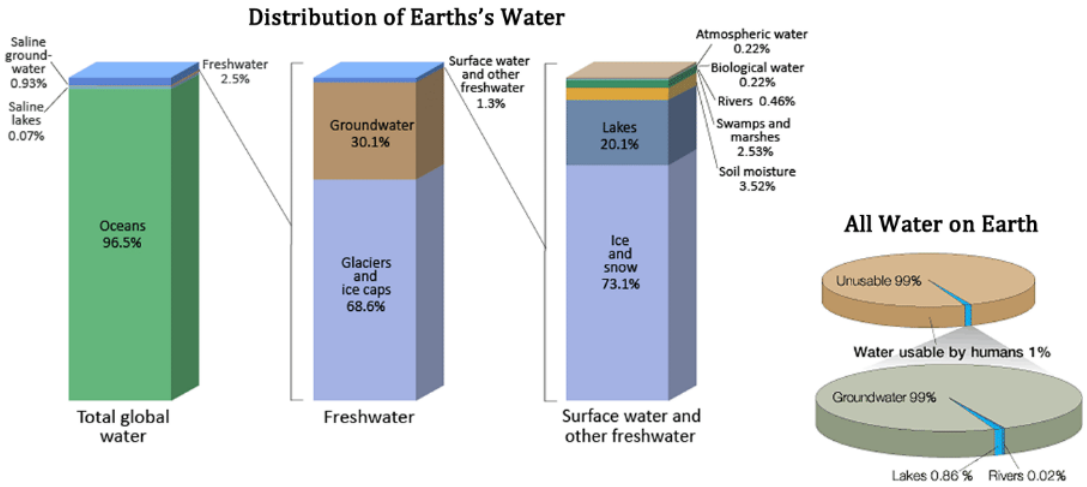


Figure 12.1.1. Earth's Water Reservoirs. Bar chart Distribution of Earth's water including total global water, fresh water, and surface water and other fresh water and Pie chart Water usable by humans and sources of usable water. Source: United States Geographical Survey Igor Skiklomanov's chapter "World 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).



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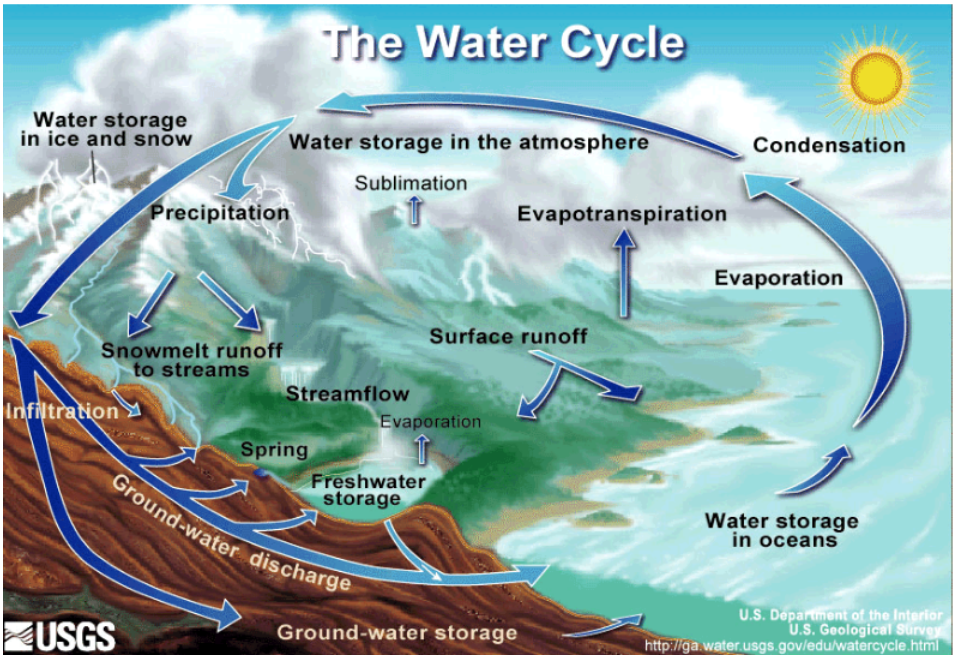


Figure 12.1.2. The Water Cycle. Arrows depict movement of water to different reservoirs located above, at, and below Earth's surface. Source: United States Geological Survey

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 12.1.3). 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.

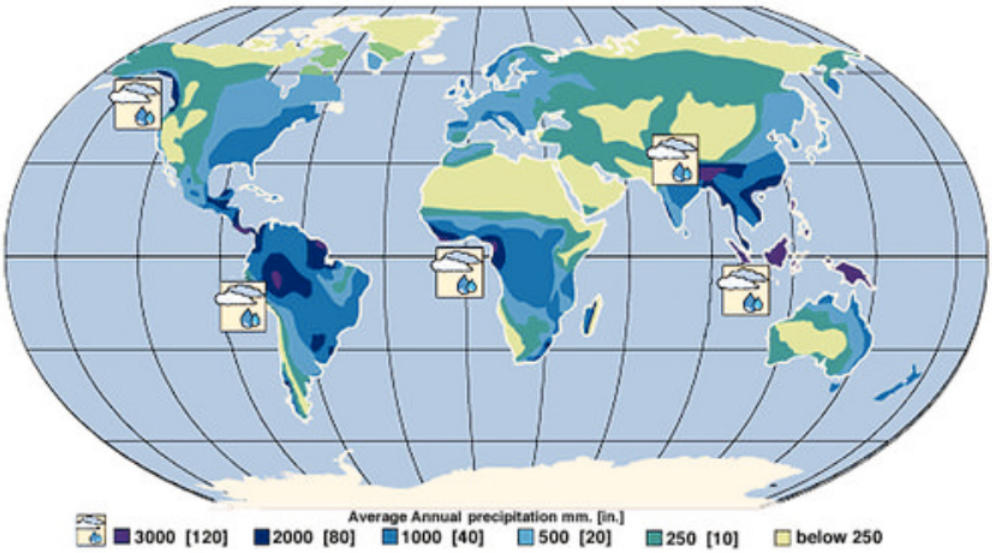


Figure 12.1.3. World Rainfall Map. The false-color map above shows the amount of rain that falls around the world. Areas of high rainfall include Central and South America, western Africa, and Southeast Asia. Since these areas receive so much rainfall, they are where most of the world's rainforests grow. 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

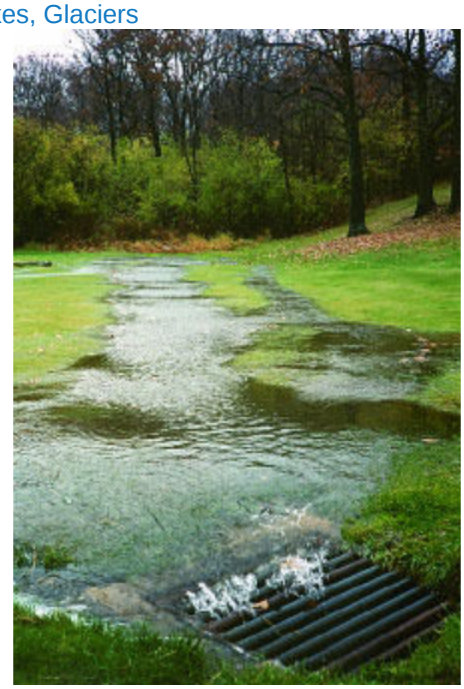


Figure 12.1.4. Surface Runoff Surface runoff, part of overland flow in the water cycle Source: James M. Pease at Wikimedia Commons

Flowing water from rain and melted snow on land enters river channels by surface runoff (Figure 12.1.4) and groundwater seepage (Figure 12.1.5). **River discharge** describes the volume of water moving through a river channel over time (Figure 12.1.6). 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

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 12.1.5. 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 12.1.6. 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 Wikimedia Commons.



Figure 12.1.7. 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.





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.

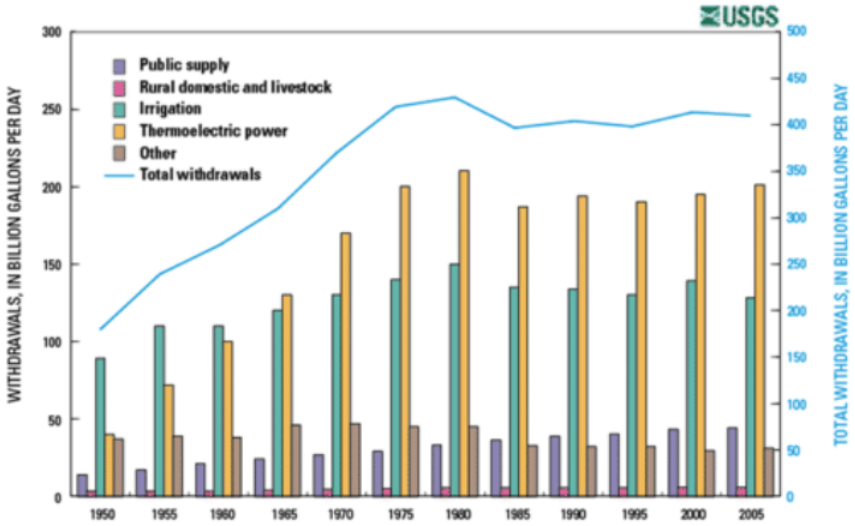


Figure 12.1.8. Trends in Total Water Withdrawals by Water-use Category, 1950-2005 Trends in total water withdrawals in the U.S. from 1950 to 2005 by water use category, including bars for thermoelectric power, irrigation, public water supply, and rural domestic and livestock. Thin blue line represents total water withdrawals using vertical scale on right. Source: United States Geological Survey

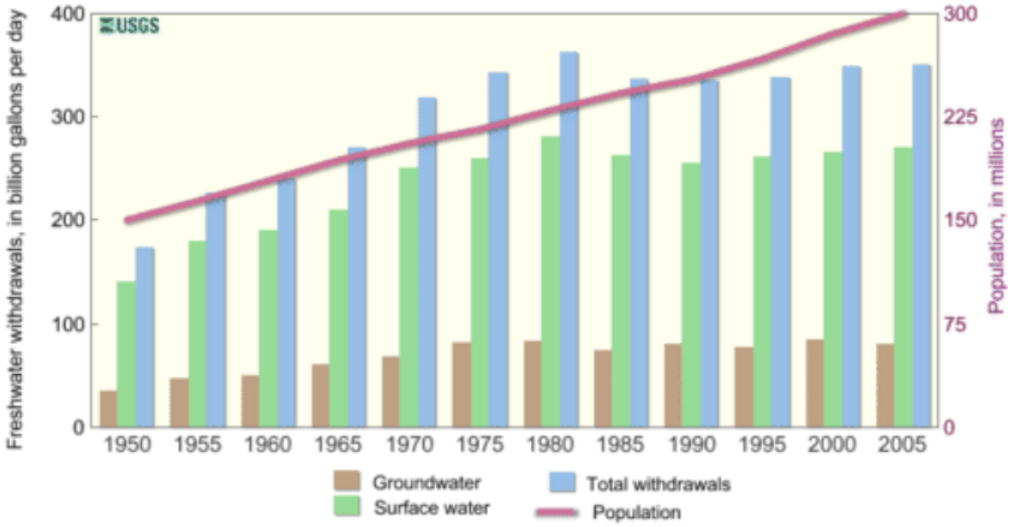


Figure 12.1.9. Trends in Source of Fresh Water Withdrawals in the U.S. from 1950 to 2005 Trends in source of fresh water withdrawals in the U.S. from 1950 to 2005, including bars for surface water, groundwater, and total water. Red line gives U.S. population using vertical scale on right. Source: United States Geological Survey

Global total water use is steadily increasing at a rate greater than world population growth (Figure 12.1.10). 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%).

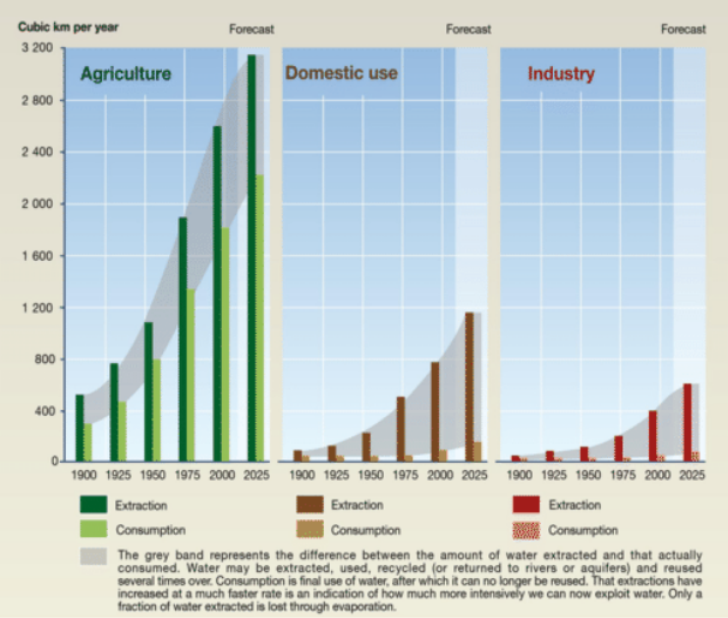


Figure 12.1.10. Trends in World Water Use from 1900 to 2000 and Projected to 2025 For each water major use category, including trends for agriculture, domestic use, and industry. Darker colored bar represents total water extracted for that use category and lighter colored bar represents water consumed (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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12.2: 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 next 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.

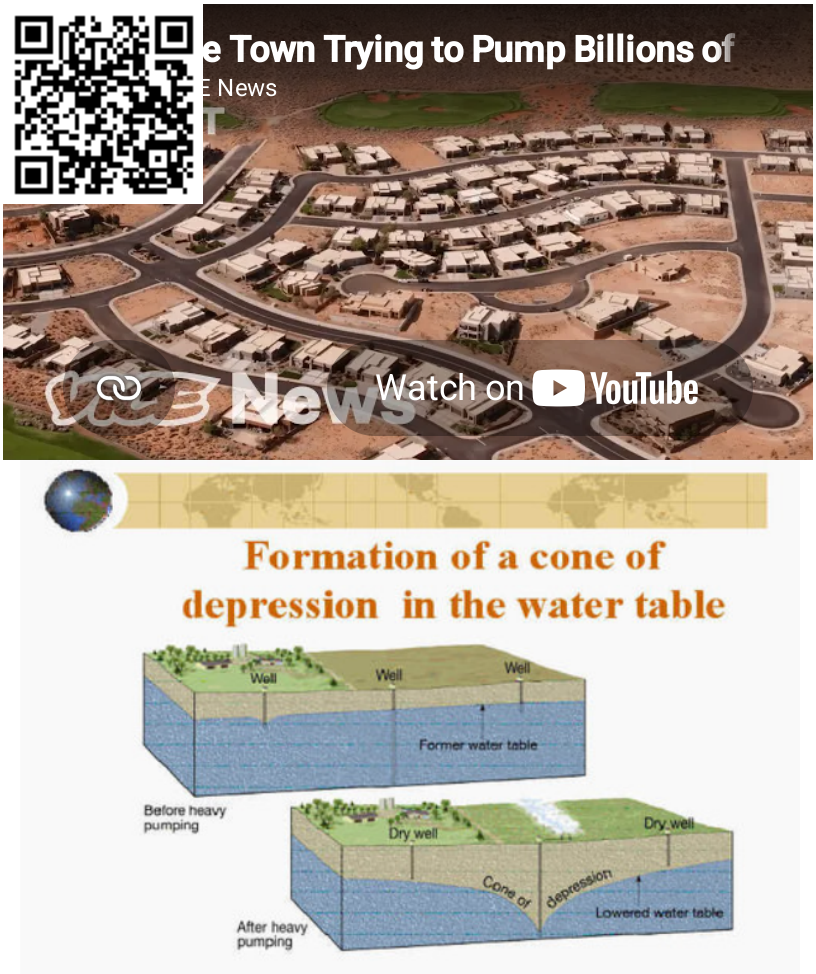


Figure 12.2.1. Formation of a Cone of Depression around a Pumping Water Well Source: Fayette County Groundwater Conservation District, TX

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.



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.

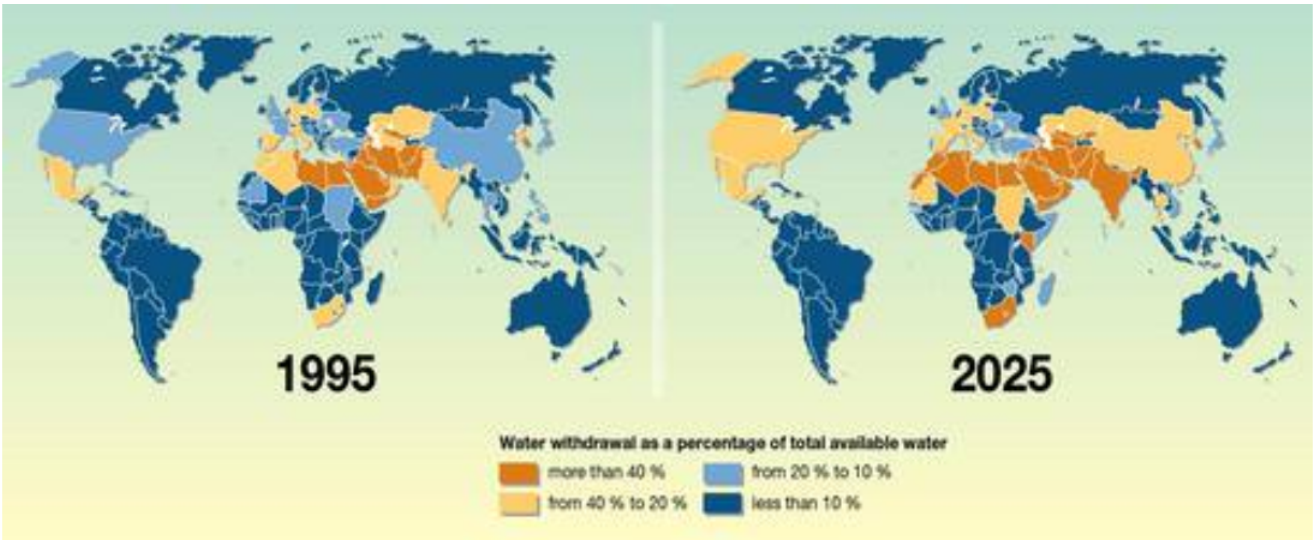


Figure 12.2.2. Countries Facing Water Stress in 1995 and Projected in 2025 Water stress is defined as having a high percentage of water withdrawal compared to total available water in the area. Source: Philippe Rekacewicz (Le Monde diplomatique), February 2006

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).



Domestic and Industrial Water Use

Water is important for all types of industries (i.e., manufacturing, transportation and mining). Manufacturing sites are often located near sources of water. Among other properties, water is an excellent and inexpensive solvent and coolant. Many manufactured liquid products have water as their main ingredient. Chemical solutions used in industrial and mining processes usually have an aqueous base. Manufacturing equipment is cooled by water and cleaned with water. Water is even used as a means of transporting goods from one place to another in manufacturing. Nuclear power plants use water to moderate and cool the reactor core as well as to generate electricity. Industry would literally come to a standstill without water.

People use water for domestic purposes such as personal hygiene, food preparation, cleaning, and gardening. Developed countries, especially the United States, tend to use a great deal of water for domestic purposes.

Water used for personal hygiene accounts for the bulk of domestic water use. For example, the water used in a single day in sinks, showers, and toilets in Los Angeles would fill a large football stadium. Humans require a reliable supply of potable water; otherwise serious health problems involving water-borne diseases can occur. This requires the establishment and maintenance of municipal water treatment plants in large populated areas.

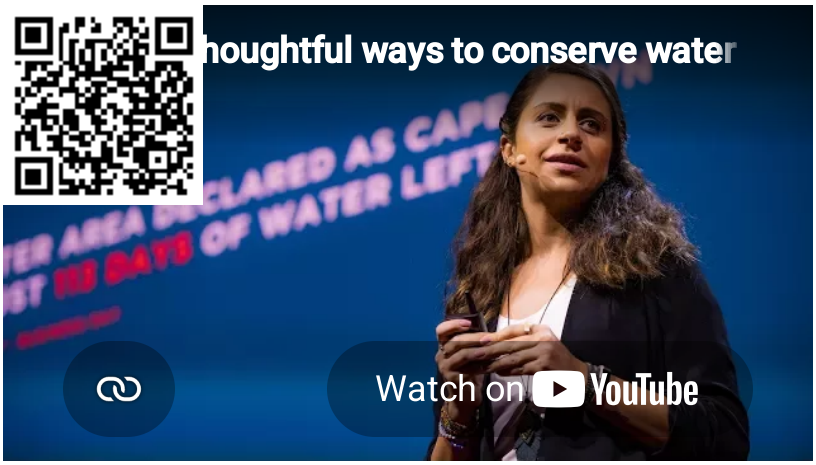
Much clean water is wasted in industrial and domestic use. In the United States this is mainly due to the generally low cost of water. Providing sufficient quantities of clean water in large population areas is becoming a growing problem, though. Conservation measures can minimize the problem: redesigning manufacturing processes to use less water; using vegetation for landscaping in arid regions that requires less water; using water-conserving showers and toilets and reusing gray water for irrigation purposes.

SUSTAINABLE(?) SOLUTIONS TO WATER SUPPLY CRISES

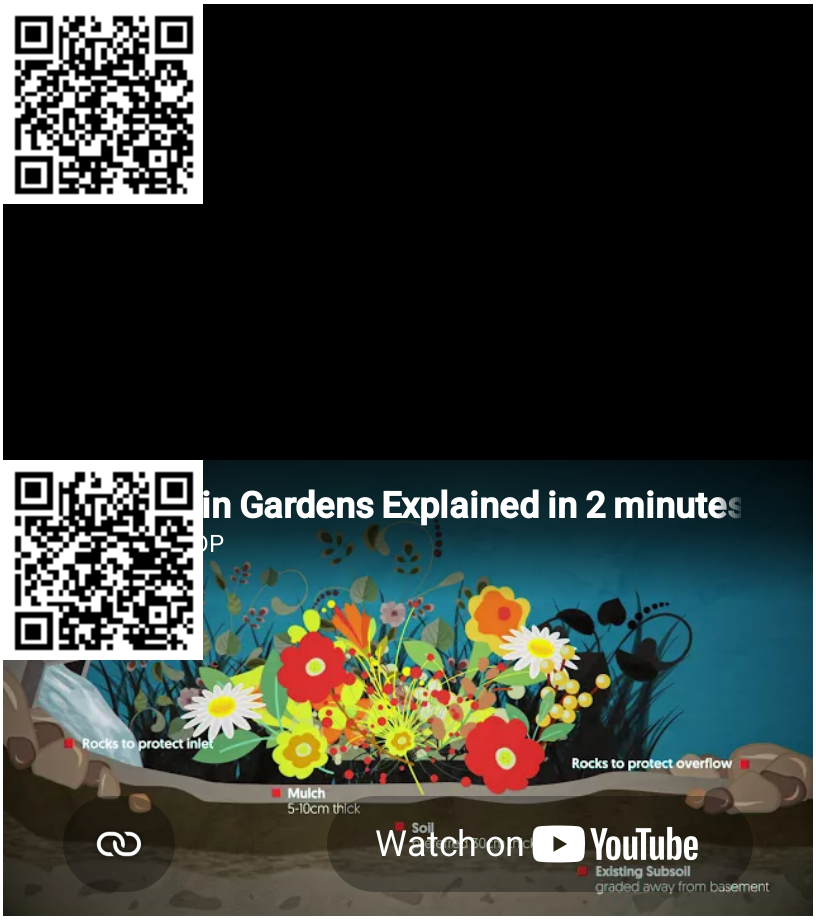
Households and industry both depend on reliable supplies of clean water. Therefore, the management and protection of water resources is important. The current and future water crises described above require multiple approaches to extending our fresh water supply and moving towards sustainability.

Conservation and Rainwater Harvesting

Water conservation is the least expensive and easiest way to extend water supplies for those who live in an area and have the means to do it. This involves using less water and using it more efficiently. Around the home, conservation is primarily behavioral, such as not watering lawns during dry spells, turning off water when not using it and taking shorter showers, fixing leaky faucets and pipes, etc. It can also involve engineered features, such as high-efficiency clothes washers and low-flow showers and toilets, and replacing lawn and non-native plants with native vegetation that requires very little (if any) irrigation.



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.





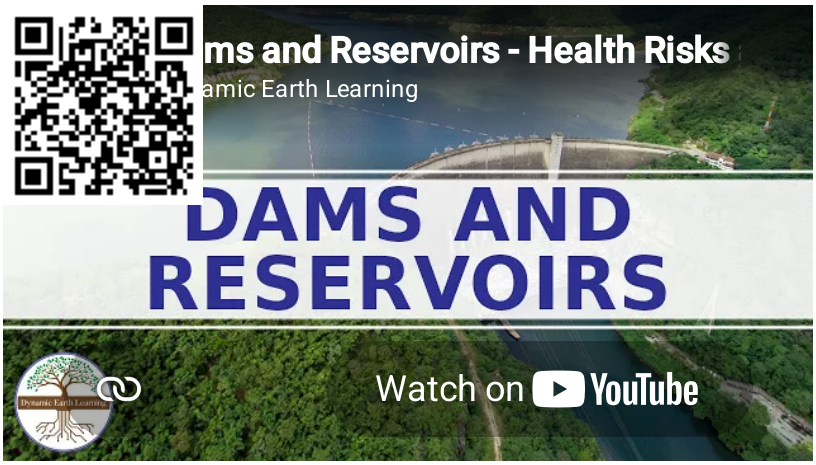
Dams, Reservoirs, and Aqueducts

Some of the longstanding traditional approaches include dams and aqueducts. Constructing dams across flowing rivers or streams and impounding the water in reservoirs is a popular way to control water resources. Dams have several advantages: they allow long-term water storage for agricultural, industrial and domestic use; they can provide hydroelectric power production and downstream flood control. However, dams disrupt ecosystems, they often displace human populations and destroy good farmland, and eventually they fill with silt.



Figure 12.2.3. Hoover Dam, Nevada, U.S. Behind the dam is Lake Mead, the largest reservoir in the U.S. White band reflects the lowered water levels in the reservoir due to drought conditions from 2000 to 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 can also 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 a 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 that the water diversion can cause drought in the area where the water is drawn from. 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.

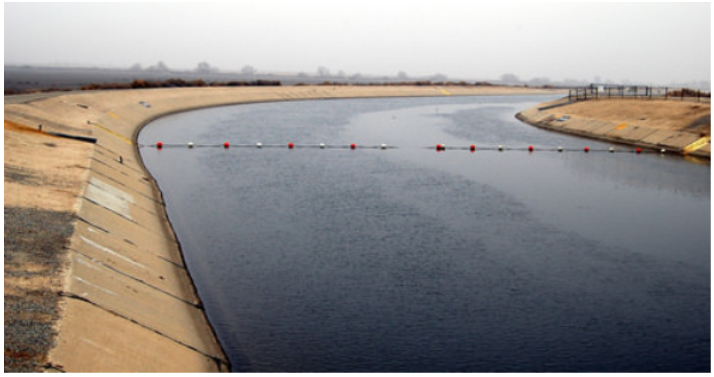


Figure 12.2.4. The California Aqueduct California Aqueduct in southern California, U.S. Source: David Jordan at en.Wikipedia

Desalination

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.

Control of Water Resources

Humans often tap into the natural water cycle by collecting water in man-made reservoirs or by digging wells to remove groundwater. Water from those sources is channeled into rivers, man-made canals or pipelines and transported to cities or agricultural lands. Such diversion of water resources can seriously affect the regions from which water is taken. For example, the Owens Valley region of California became a desert after water projects diverted most of the Sierra Nevada runoff to the Los Angeles metropolitan area. This brings up the question of who owns (or has the rights to) water resources.

Water rights are usually established by law. In the eastern United States, the "**Doctrine of Riparian Rights**" is the basis of rights of use. Anyone whose land is next to a flowing stream can use the water as long as some is left for people downstream. Things are handled differently in the western United States, which uses a "first-come, first-served" approach known as the "**Principle of Prior Appropriation**". By using water from a stream, the original user establishes a legal right for the ongoing use of the water volume originally taken. Unfortunately, when there is insufficient water in a stream, downstream users suffer.

The case of the Colorado River highlights the problem of water rights. The federal government built a series of dams along the Colorado River, which drains a huge area of the southwestern United States and northern Mexico. The purpose of the project was to provide water for cities and towns in this arid area and for crop irrigation. However, as more and more water was withdrawn from these dams, less water was available downstream. Only a limited volume of water reached the Mexican border, and this was saline and unusable. The Mexican government complained that its country was being denied use of water that was partly theirs, and as a result, a desalination plant was built to provide a flow of usable water.

Common law generally gives property owners rights to the groundwater below their land. However, a problem can arise in a situation where several property owners tap into the same groundwater source. The Ogallala Aquifer, which stretches from Wyoming to Texas, is used extensively by farmers for irrigation. However, this use is leading to groundwater depletion, as the aquifer has a very slow recharge rate. In such cases as this, a general plan of water use is needed to conserve water resources for future use.









Water Diversion

Water is necessary for all life, as well as for human agriculture and industry. Great effort and expense has gone into diverting water from where it occurs naturally to where people need it to be. The large-scale redistribution of such a vital resource has consequences for both people and the environment. The three projects summarized below illustrate the costs and benefits and complex issues involved in water diversion.

Garrison Diversion Project

The purpose of the Garrison Diversion Project was to divert water from the Missouri River to the Red River in North Dakota, along the way irrigating more than a million acres of prairie, attracting new residents and industries, and providing recreation opportunities.

Construction began in the 1940s, and although $600 million has been spent, only 120 miles of canals and a few pumping stations have been built. The project has not been completed due to financial problems and widespread objections from environmentalists, neighboring states, and Canada. Some object to flooding rare prairie habitats. Many are concerned that moving water from one watershed to another will also transfer non-native and invasive species that could attack native organisms, devastate habitats, and cause economic harm to fishing and other industries. As construction and maintenance costs skyrocketed, taxpayers expressed concern that excessive public money was being spent on a project with limited public benefits.

Melamchi Water Supply Project

The Kathmandu Valley in Nepal is an important urban center with insufficient water supplies. One million people receive piped water for just a few hours a day. Groundwater reservoirs are being drained, and water quality is quite low. The Melamchi Water Supply Project will divert water to Kathmandu through a 28 km tunnel from the Melamchi River in a neighboring valley. Expected to cost half a billion dollars, the project will include improved water treatment and distribution facilities.

While the water problems in the Kathmandu Valley are severe, the project is controversial. Proponents say it will improve public health and hygiene and stimulate the local economy without harming the Melamchi River ecosystem. Opponents suggest that the environmental safeguards are inadequate and that many people will be displaced. Perhaps their biggest objection is that the project will privatize the water supply and raise costs beyond the reach of the poor. They claim that cheaper and more efficient alternatives have been ignored at the insistence of international banks, and that debt on project loans will cripple the economy.





South to North Water Diversion Project

Many of the major cities in China are suffering from severe water shortages, especially in the northern part of the country. Overuse and industrial discharge has caused severe water pollution. The South to North Water Diversion project is designed to shift enormous amounts of water from rivers in southern China to the dry but populous northern half of the country. New pollution control and treatment facilities to be constructed at the same time should improve water quality throughout the country.

The diversion will be accomplished by the creation of three rivers constructed by man, each more than 1,000 km long. They will together channel nearly 50 billion cubic meters of water annually, creating the largest water diversion project in history.

Construction is expected to take 10 years and cost $60 billion, but after 2 years of work, the diversion is already over budget.

Such a massive shift in water resources will have large environmental consequences throughout the system. Water levels in rivers and marshes will drop sharply in the south and rise in the north. People and wildlife will be displaced along the courses of the new rivers.

Despite its staggering scale, the South to North Project alone will not be sufficient to solve water shortages. China still will need to increase water conservation programs, make industries and agriculture more water efficient, and raise public awareness of sustainable water practices.

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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12.3: 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 12.3.2. 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 12.3.3. 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.

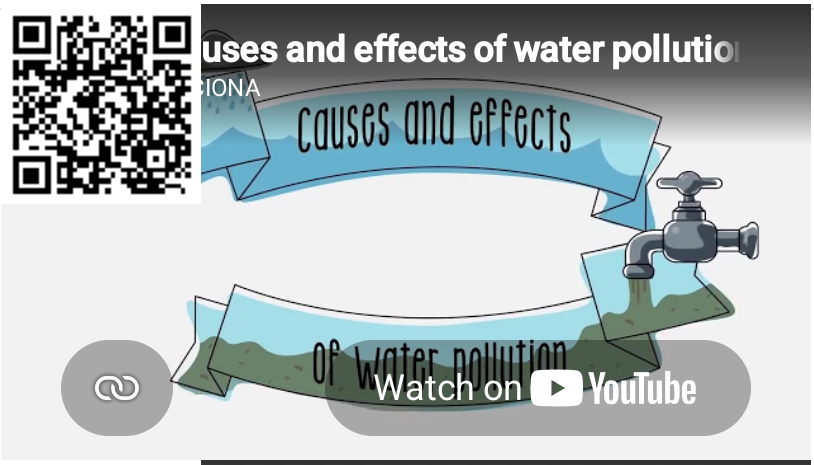
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12.4: Water Pollution





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 12.4.1). 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.

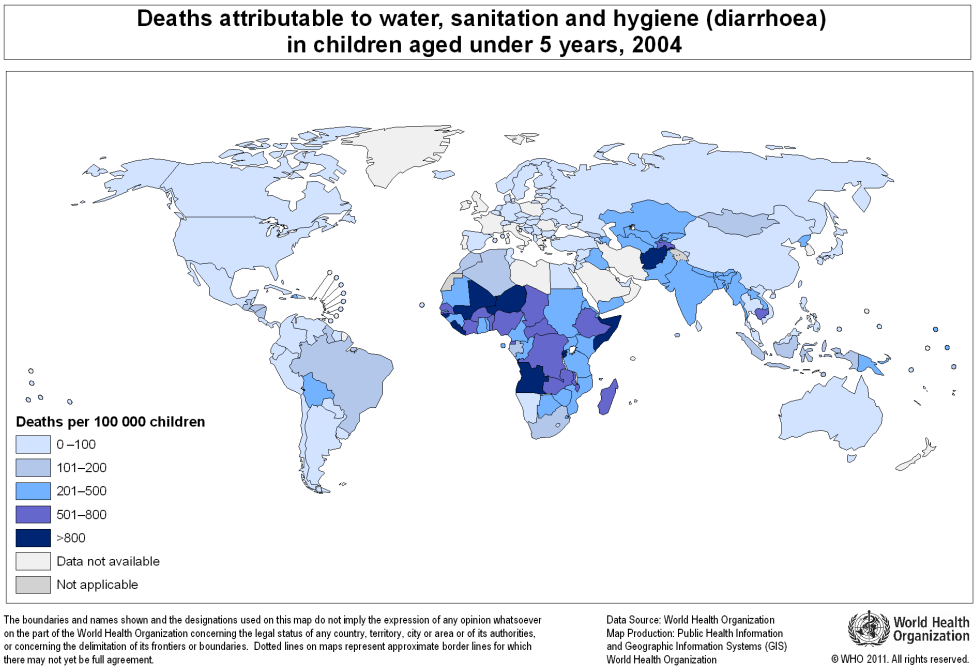


Figure 12.4.1. This work was created by the *World Health Organization*.

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.

Water Pollution Overview



Figure 12.4.2. 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 12.4.2). Water pollutants can move through different water reservoirs, as the water carrying them progresses through stages of the water cycle (Figure 12.4.3). **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.

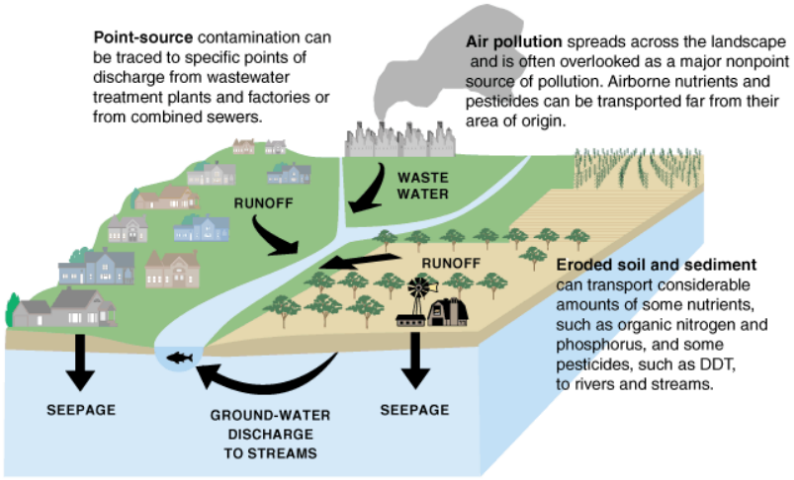


Figure 12.4.3. Sources of Water Contamination. Sources of some water pollutants and movement of pollutants into different water reservoirs of the water cycle. Source: U.S. Geological Survey

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 12.4.4) that raise a large number and high density of livestock such as cows, pigs, and chickens. Also, pipes included are pipes from a factories 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 12.4.5).



Figure 12.4.4. 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.

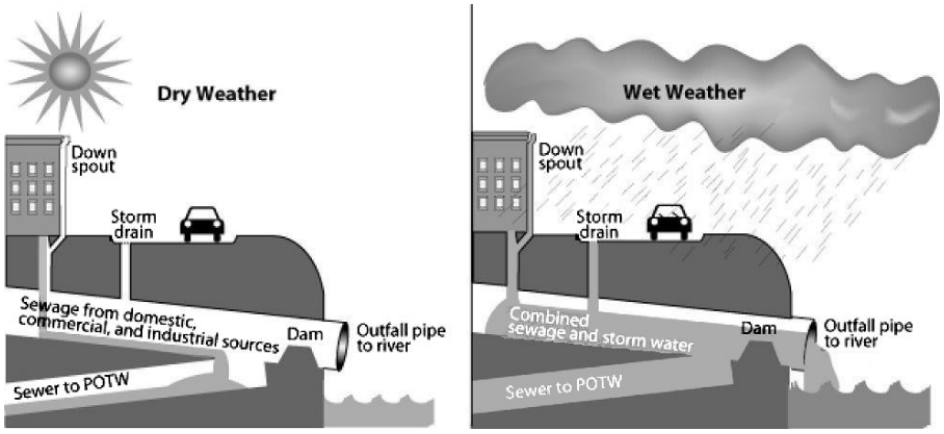


Figure 12.4.5. Combined Sewer System A combined sewer system is a possible major point source of water pollution during heavy rain due to overflow of untreated sewage. During dry weather (and small storms), all flows are handled by the publicly owned treatment works (POTW). During large storms, the relief 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

Plastics and Other Solids



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:

$$\text{organic matter} + O_2 \rightarrow CO_2 + H_2O \tag{12.4.1}$$

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 12.4.6) 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 12.4.6. 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). Other fossil fuels can also contribute to water pollution.



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.

Lead pollution:



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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12.5: 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 12.5.1).



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.

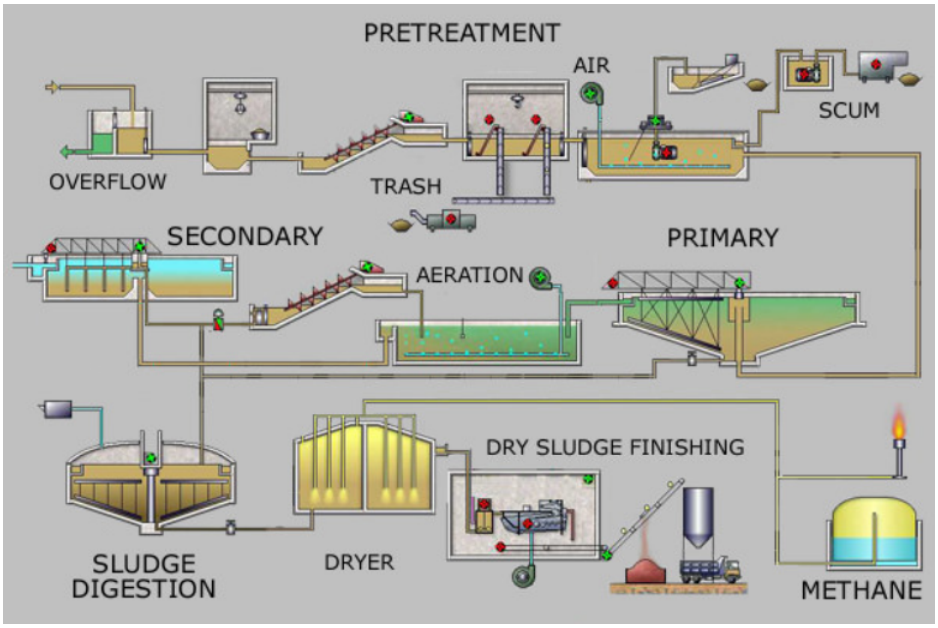


Figure 12.5.1. Steps at a Sewage Treatment Plant The numerous processing steps at a conventional sewage treatment plant include pretreatment (screening and removal of sand and gravel), primary treatment (settling or floatation to remove organic solids, fat, and grease), secondary treatment (aerobic bacterial 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 12.5.2) 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.

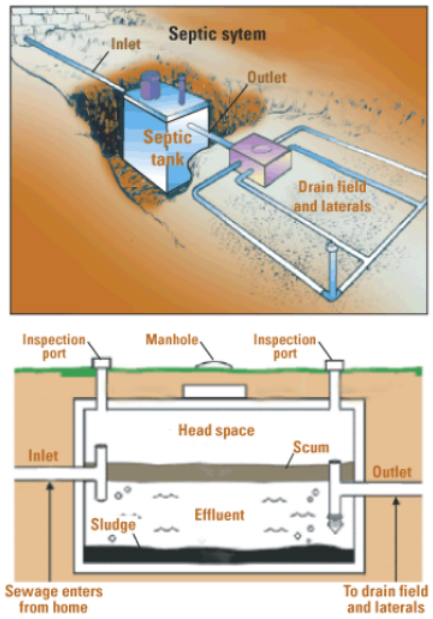


Figure 12.5.2. Septic System Septic tank system for sewage treatment. Source: United States Geological Survey

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

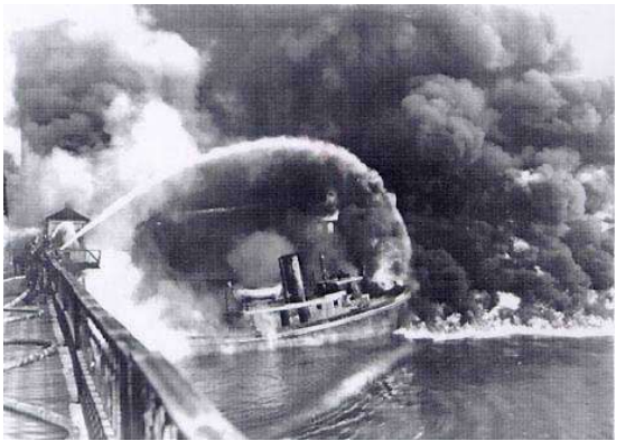
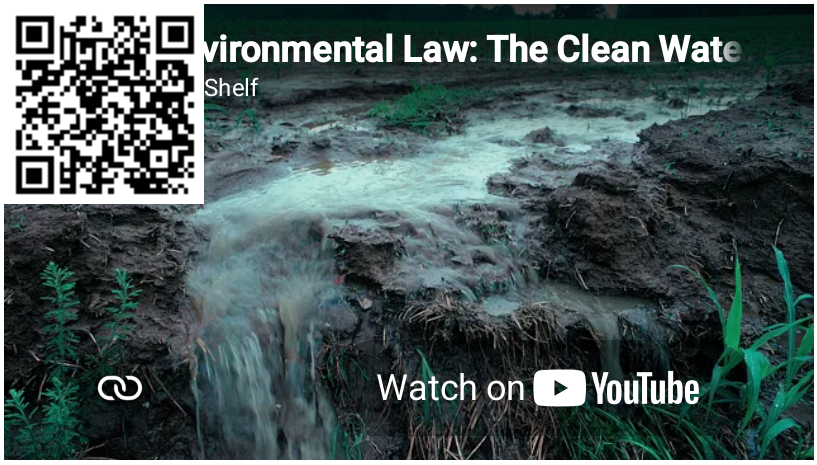
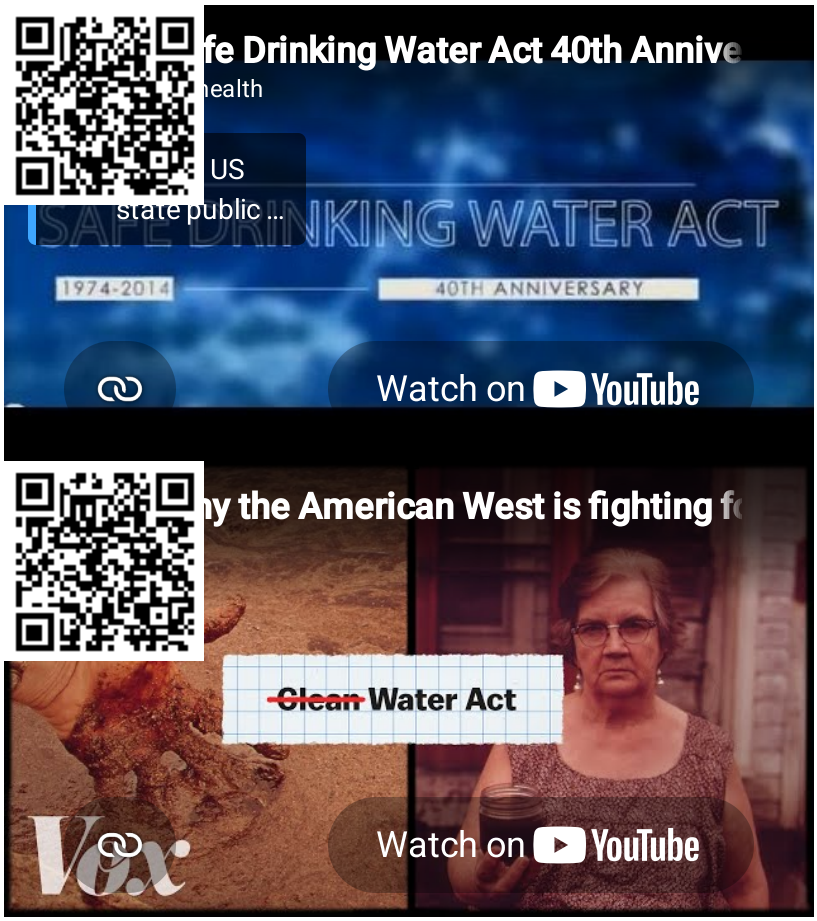


Figure 12.5.3. Cuyahoga River on fire. Source: National Oceanic and Atmospheric Administration

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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12.6: 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. 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
3. 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
4. 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.
5. 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

6. 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
7. 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

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

13: Solid, Toxic, and Hazardous Waste

Chapter Hook

Flushable wipes, are flushable right? No. Over and over, plumbers and waste water treatment workers state that they do not degrade fast enough and clogs drains and sewers across the globe. Not all flushable wipes are created equal, and some are better than others. Unfortunately, there are no legal requirements these products are required to passed to be called flushable, and the only guiding body is the integrity of the company manufacturing the wipes. If you want advice about your body you go to your doctor. If you want advice about your pipes, talk to your plumber. They will tell you that the only things that should go down your toilet are the 3 P's, pee, poo, and (toilet) paper.



Figure 13.a: Wipe isle at the store. Image by 維基小霸王 in Wikimedia Commons (CC-BY-SA4.0)

13.1: Waste Generation

13.2: Waste Disposal

13.3: Solid Waste and Marine Life

13.4: Waste Reduction

13.S: Review

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13.1: Waste Generation

INTRODUCTION

In natural systems, there is no such thing as waste. Everything flows in a natural cycle of use and reuse. Living organisms consume materials and eventually return them to the environment, usually in a different form, for reuse. **Solid waste** (or trash) is a human concept. It refers to a variety of discarded materials, not liquid or gas, that are deemed useless or worthless (figure 13.1.a). Humans modify natural substances, making them more difficult to breakdown, or store matter under conditions that slow its degradation. However, what is worthless to one person may be of value to someone else, and solid wastes can be considered misplaced resources. Learning effective ways to reduce the amount of wastes produced and to recycle valuable resources contained in the wastes is important if humans wish to maintain a livable and sustainable environment.



Figure 13.1.a: Trash is a uniquely human concept. Image by Piqsels (public domain).

Solid waste disposal has been an issue facing humans since they began living together in large, permanent settlements. With the migration of people to urban settings, the volume of solid waste in concentrated areas greatly increased.

Ancient cultures dealt with waste disposal in various ways: they dumped it outside their settlements, incorporated some of it into flooring and building materials, and recycled some of it. Dumping and/or burning solid waste has been a standard practice over the centuries. Most communities in the United States dumped or burned their trash until the 1960s, when the Solid Waste Disposal Act of 1965 (part of the Clean Air Act) required environmentally sound disposal of waste materials.



SOURCES AND TYPES OF SOLID WASTE

There are two basic sources of solid wastes: non-municipal and municipal. **Non-municipal solid waste** is the discarded solid material from industry, agriculture, mining, and oil and gas production. It makes up almost 99 percent of all the waste in the United States. Some common items that are classified as non-municipal waste are: construction materials (roofing shingles, electrical

fixtures, bricks); waste-water sludge; incinerator residues; ash; scrubber sludge; oil/gas/mining waste; railroad ties, and pesticide containers.

Municipal solid waste is made up of discarded solid materials from residences, businesses, and city buildings. It makes up a small percentage of waste in the United States, only a little more than one percent of the total. Municipal solid waste consists of materials from plastics to food scraps. The most common waste product is paper (about 40 percent of the total).

Other common components are: yard waste (green waste), plastics, metals, wood, glass and food waste. The composition of the municipal wastes can vary from region to region and from season to season. Food waste, which includes animal and vegetable wastes resulting from the preparation and consumption of food, is commonly known as garbage.

Types of Waste

There are many subcategories of waste (figure 13.1.*b*). **Biodegradable** waste can be broken down by microbes whereas **nondegradable** waste does not readily break down. **Hazardous waste** is trash that presents a health risk. Specifically, hazardous wastes are defined as materials which are toxic, **carcinogenic** (cause cancer), **mutagenic** (cause DNA mutations), **teratogenic** (cause birth defects), highly flammable, corrosive, or explosive. Examples include batteries, fluorescent lights, various cleaners, and **e-waste**, which arises from discarded electronics. Precious metals can be extracted and recycled from hazardous waste, but it must be done safely.



Figure 13.1.*b*: Plastic cutlery is nondegradable, but these spoons and forks and made of wood, a biodegradable material. Image by BRRT/Pixabay (Pixabay license).

Solid Waste Sources and Composition

Agriculture and industry generate most of the waste globally followed by mining (figure 13.1.*c*). Together, these generate **non-municipal solid waste**. Some common items that are classified as non-municipal waste are: construction materials (roofing shingles, electrical fixtures, bricks); waste-water sludge; incinerator residues; ash; scrubber sludge; oil/gas/mining waste; railroad ties, and pesticide containers. The remaining waste, **municipal solid waste** (MSW), is made up of discarded solid materials from residences, businesses, and city buildings. Globally, waste generated from industry generated was nearly 18 times that of MSW, and waste generated from agriculture was more than 4.5 times that of MSW.

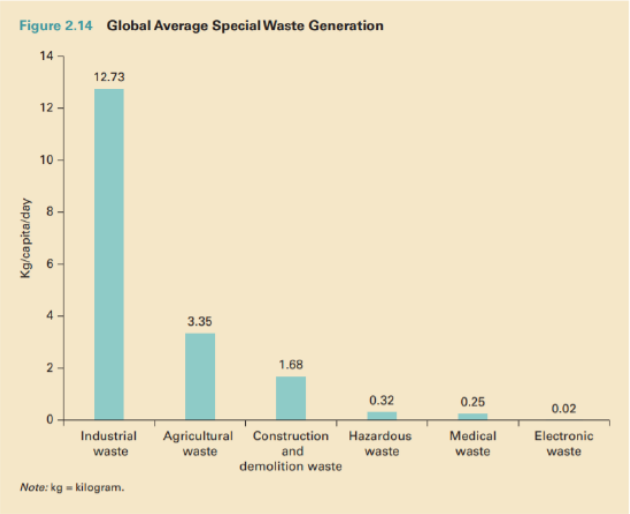


Figure 13.1.*c*: Global average special waste generation showing selected categories of waste in kilograms (kg) per person (capita) per day. 1 kg = 2.2 lbs. In order of greatest to least waste generation is industrial waste (12.73 kg/capita/day), agricultural waste (3.35), construction and demolition waste (1.68), hazardous waste (0.32), medical waste (0.25), and electronic waste (0.02). Image from What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (CC-BY)

The world generates 2.21 billion tons of municipal solid waste annually. Municipal solid waste makes up 3-9% of all waste in the U.S., and 292.4 million tons were generated in U.S. in 2018 (4.9 lbs per person per day). This contrasts with the average values in Sub-Saharan Africa (1.01 pounds per person per day), South Asia (1.15 pounds per person per day), and East Asia and the Pacific (1.23 pounds per person per day). Daily waste generation per person in high-income countries is projected to increase by 19% by 2050, compared to low- and middle-income countries, where it is anticipated to increase by approximately 40% or more.

Municipal solid waste consists of materials from plastics to food scraps. The most common waste products are food and yard trimmings (a combined ~34% of the total in 2018, the last year that figures are available from the EPA; figure 13.1.*d*). Both of these are completely compostable. Other common components include paper (which is also largely compostable), plastics, metals, wood, glass, and textiles. The composition of the municipal wastes can vary from region to region and from season to season.

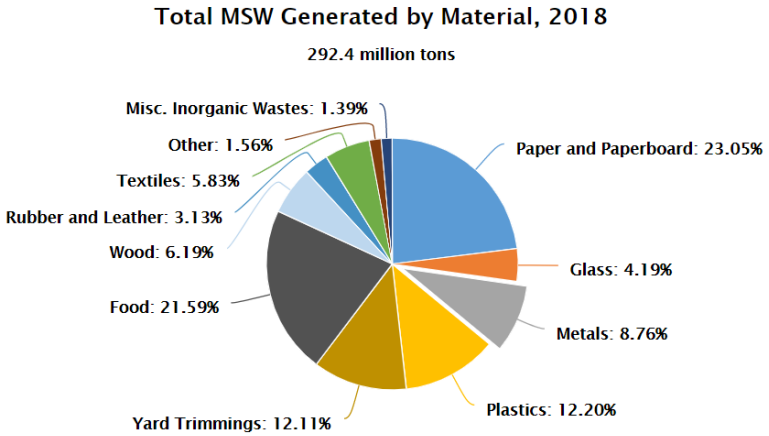


Figure 13.1.*d*: Composition of municipal solid waste (MSW) in the U.S. in 2018 before recycling. Paper and paperboard comprise 23.05% followed by food (21.59%), plastics (12.20%), yard trimmings (12.11%), metals (8.76%), wood (6.19%), textiles (5.83%), glass (4.19%), rubber and leather (3.13%), other (1.56%), and miscellaneous inorganic waste (1.39%). Image from EPA (public domain).

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- Kaza, Silpa; Yao, Lisa C.; Bhada-Tata, Perinaz; Van Woerden, Frank. 2018. What a Waste 2.0 : A Global Snapshot of Solid Waste Management to 2050. Urban Development;. Washington, DC: World Bank. © World Bank. (CC-BY)

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13.2: Waste Disposal

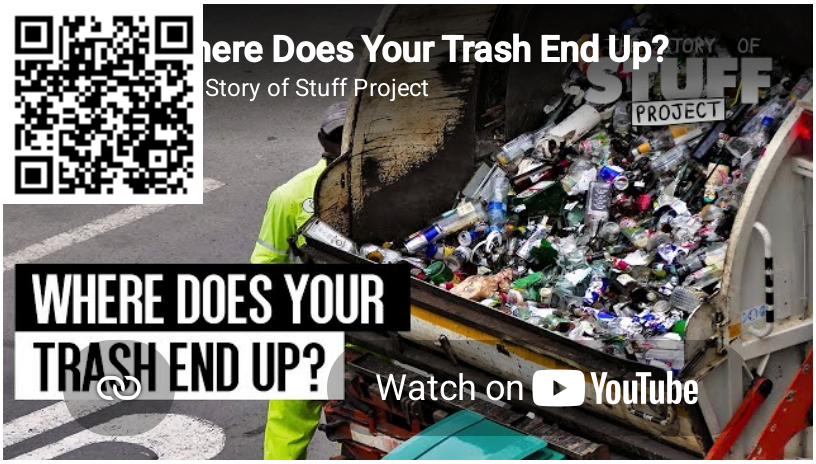
There are three primary methods for waste disposal: open dumps, sanitary landfills, and incineration. Sanitary landfills and incineration prevent reuse, recycling, and proper decomposition. While open dumps promote decomposition better than other methods of waste disposal and allow discarded materials to be salvaged or recycled, they promote disease spread and cause water pollution. They are thus illegal in many countries.

Open Dumps

Open dumps involve simply piling up trash in a designated area and is thus the easiest method of waste disposal (figure 13.2.a). Open dumps can support populations of organisms that house and transmit disease (reservoirs and vectors, respectively). Additionally, contaminants from the trash mix with rain water forming **leachate**, which infiltrates into the ground or runs off. This liquid leachate may contain toxic chemicals such as dioxin (a persistent organic pollutant), mercury, and pesticides.



Figure 13.2.a: An open dump in Vietnam. Image by Julien Belli (CC-BY).



Sanitary Landfills

After recycling, composting, and incineration, the remaining 50% of municipal solid waste (MSW) in the U.S. was discarded in **sanitary landfills** (figure 13.2.b). Trash is sealed from the top and the bottom to reduce contamination of surroundings (figure 13.2.c). Rainwater that percolates through a sanitary landfill is collected in the bottom liner, and this bottom layer thus prevents contamination of groundwater. The groundwater near the landfill is closely monitored for signs of contamination from the leachate. Layers of soil on top prevent disease spread. Each day after garbage is dumped in the landfill, it is covered with clay or plastic to prevent redistribution by animals or the wind.



Figure 13.2.*b*: A sanitary landfill in 1972. Image by Bill Shrout/EPA (public domain).

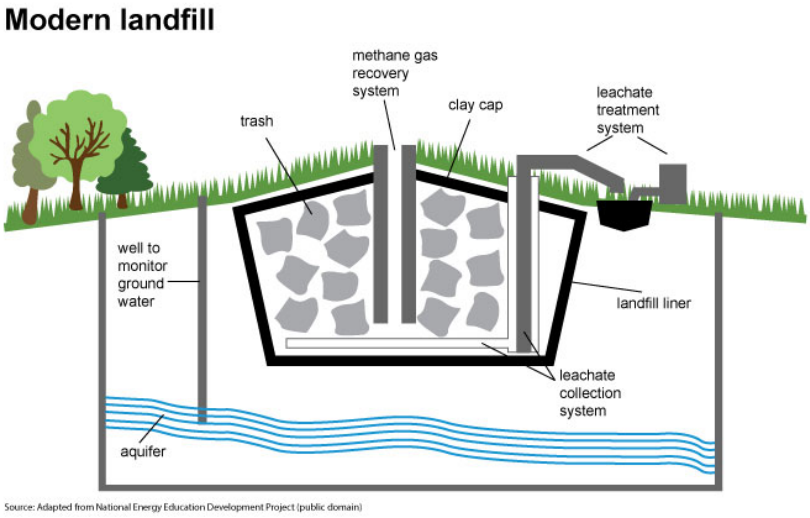


Figure 13.2.*c*: A sanitary landfill. Trash is compacted and stored underground. A landfill liner prevents leachate from draining into the aquifer and contaminating groundwater, which is monitored using a well. Additionally, leachate is collected and treated (leachate treatment system). A clay cap prevents animals or wind from accessing the trash. A methane gas recovery system captures the potent greenhouse gas, which can be used as a biofuel. Image by EPA/National Energy Education Development Project (public domain).

Several practices can reduce the environmental impact of sanitary landfills. Compacting in landfills reduces water and oxygen levels, slowing decomposition and promoting methane release. In the U.S., the Clear Air Act requires that landfills of a certain size collect landfill gas (biogas), which can be used as a biofuel for heating or electricity generation. Other gases such as ammonia and hydrogen sulfide may also be released by the landfill, contributing to air pollution. These gases are also monitored and, if necessary, collected for disposal. To address the often dry condition of wastes within landfills, the concept of bioreactor landfills has emerged. These recirculate leachate and/or inject other liquids to increase moisture and promote decomposition (and therefore increasing the rate of biogas production). Upon closure, many landfills undergo "land recycling" and can be redeveloped as golf courses, recreational parks, and other beneficial uses.

With respect to waste mitigation options, landfilling is quickly evolving into a less desirable or feasible option. Landfill capacity in the United States has been declining for several reasons. Older existing landfills are increasingly reaching their authorized capacity. Additionally, stricter environmental regulations have made establishing new landfills increasingly difficult. Finally, public opposition delays or, in many cases, prevents the approval of new landfills or expansion of existing facilities.

Incineration

Incineration is simply burning trash. This has several advantages: it reduces volume and can be used to generate electricity (**waste-to-energy**). In fact, the sheer volume of the waste is reduced by about 85%. Incineration is costly, however, and it pollutes air and water. Air pollutants released by incineration include particulates, sulfur dioxide, nitrogen oxides, methane, heavy metals (such as lead and mercury), and dioxins. The byproduct of incineration, ash, is often toxic. Depending on its composition, ash might require special disposal; other types of ash can be repurposed.

An incinerator processes trash and burns it in a **combustion chamber** (figure $13.2.d - e$). The heat boils water, and the resultant steam is used to generate electricity. The smoke (called flue gases) goes through a **pollution-removal** before it is released, but it still contains some pollutants. The U.S. incinerated 11.8% of MSW in 2018.



Figure $13.2.d$: Wheelabrator Technologies' Waste-to-Energy plant in Saugus, Massachusetts has been in service since 1975. Image and caption (modified) from Fletcher6 (CC-BY).

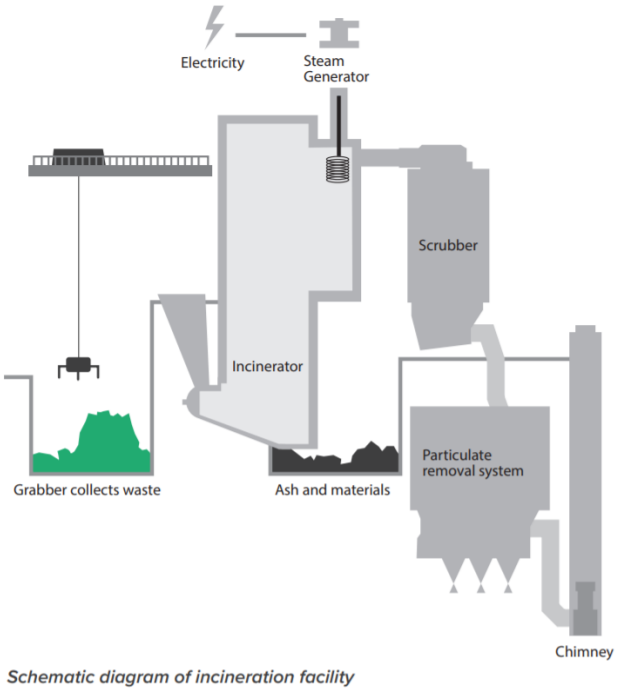


Figure $13.2.e$: A schematic diagram of a waste incineration facility (waste-to energy system). A grabber collects the waste and transfers it into the incinerator. Heat from combusting the trash is used to produce steam and generate electricity. Emissions (flue gases) pass through a scrubber and particulate removal system to limit pollution before the gases are released through a chimney. Ash remains after incineration. Image by Kaza, Silpa; Bhada-Tata, Perinaz. 2018. Decision Maker's Guides for Solid Waste

Management Technologies. Urban Development Series Knowledge Papers;. World Bank, Washington, DC. © World Bank. (CC-BY)

There are two kinds of waste-to-energy systems: mass burn incinerators and refuse-derived incinerators. In **mass burn incinerators** all of the solid waste is incinerated. The heat from the incineration process is used to produce steam. This steam is used to drive electric power generators. Acid gases from the burning are removed by chemical scrubbers. Any particulates (small particles that remain suspended in the air) in the combustion gases are removed by **electrostatic precipitators**, which charge particulates and remove them with electrodes. The cleaned gases are then released into the atmosphere through a tall stack. The ashes from the combustion are sent to a landfill for disposal.

It is best if only combustible items (paper, wood products, and plastics) are burned. In a **refuse-derived incinerator**, non-combustible materials are separated from the waste. Items such as glass and metals may be recycled. The combustible wastes are then formed into fuel pellets which can be burned in standard steam boilers. This system has the advantage of removing potentially harmful materials from waste before it is burned. It also provides for some recycling of materials.

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- Biomass explained: Landfill gas and biogas. 2020. EIA. Accessed 01-18-2021 (public domain).

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13.3: Solid Waste and Marine Life

Ocean dumping has also been a popular way for coastal communities to dispose of their solid wastes. In this method, large barges carry waste out to sea and dump it into the ocean (figure 13.3.a). That practice is now banned in the United States due to the pollution problems it created. However, much trash escapes to the ocean through littering and illegal dumping. Additionally, wind carries trash off of overfilled containers, landfills, or open dumps (where they are still used).



Figure 13.3.a: Left: A garbage barge leaves Manhattan. Right: Marine debris at the beach. Left image and caption by EPA (public domain), and right image and caption by NOAA (public domain).

Garbage patches form from waste that escapes to the ocean. Plastic breaks down into smaller pieces when exposed to sunlight and ample oxygen. These pieces of plastic are trapped in calm parts of the ocean that are surrounded by strong, circular currents (figure 13.3.b). Garbage patches may not be visible from the surface of the ocean, and the plastic pieces may be up to 20 meters deep.

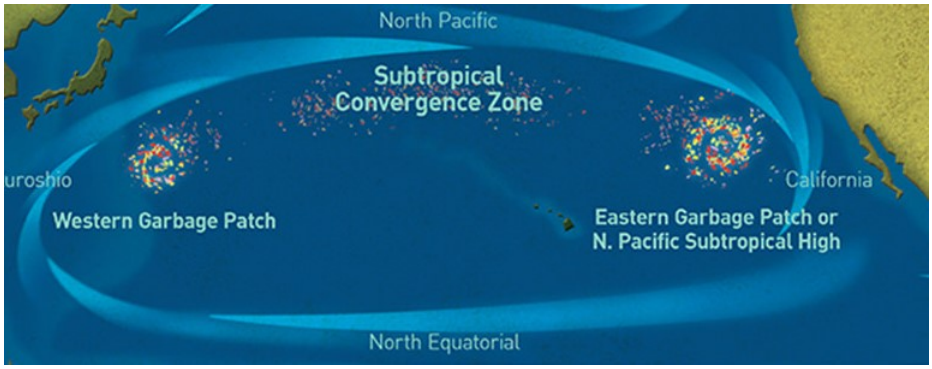


Figure 13.3.b: Locations of the largest garbage patches in the Pacific Ocean. The Western Garbage Patch is closer to Japan, and the Eastern Garbage Patch is closer to California. The Subtropical Convergence Zone is in the middle to the north. Ocean currents including the Kuroshio Current (left), North Pacific Current (top), California Current (right), and North Equatorial Current (bottom) are labeled. Image by Boyan Slat (public domain).

Plastic and other trash harms marine life in several ways. Old fishing nets and plastic six-pack rings trap wildlife. Additionally, organisms that ingest plastic risk choking. Ingested plastic may cut internal organs, limit space available for food, and carry toxins (figure 13.3.c).



Figure 13.3.*c*: Much of this dead albatross's digestive system was filled with plastic waste. Image by Forest and Kim Starr (CC-BY).

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13.4: Waste Reduction

The **waste management hierarchy** lists processes to address waste in order of preference with the goals of limiting waste, minimizing environmental impact, and maximizing additional benefits (such as electricity generation or production of recycled goods). It is symbolized as an upside triangle, meaning that the largest volume of waste should be handled using the first process (most preferred), and the smallest volume should be handled using the last process (least preferred). These processes in order of preference are reduction, recycling, energy recovery (such as incineration), treatment, and disposal (figure 13.4.*a*). Individuals can exercise the first two processes by applying the four R's (see below). Unfortunately, the U.S. and the world overall, handles a large volume of waste using the least preferred method (disposal). As previously mentioned, about half of municipal solid waste (MSW) goes to a sanitary landfill for disposal. In contrast, only 23.5% of municipal solid waste (MSW) was recovered and recycled and another 8.5% was composted in 2018. Waste stream percentages also vary widely by region. As an example, San Francisco, California recycles or composts 80% of its waste material, whereas Houston, Texas recycles or composts only 19%.

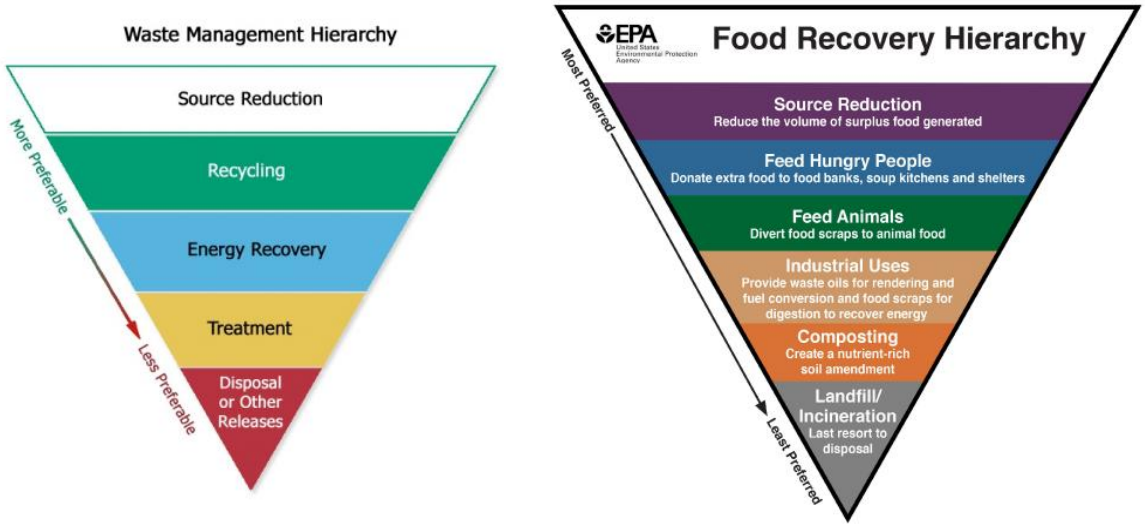


Figure 13.4.*a*: Left: The waste management hierarchy lists processes for handling waste from most to least preferable. They are source reduction, recycling, energy recovery, treatment, and disposal or other releases. Right: The food recovery hierarchy is a waste management hierarchy specific to food waste. It begins with source reduction (reduce the volume of surplus food generated). Next is feed hungry people (donate extra food to food banks, soup kitchens, and shelters. Third is feed animals (divert food scraps to animal food. Fourth is industrial uses (provide waste oils for rendering and fuel conversion and food scraps for digestion to recover energy. Fifth is composting (create a nutrient-rich soil amendment). The remaining waste goes to landfill or incineration as a last resort to disposal. Images by EPA (public domain).

Source reduction (waste minimization) refers to the strategies that minimize the amount of generated waste and/or reduce the toxicity of the resultant waste when designing or manufacturing products or services. Waste can be reduced by reusing materials, using less hazardous substitute materials, or by modifying components of design and processing. Source reduction in manufacturing not only saves resources, but it also reduces costs for the manufacturer and indirectly for the consumer. For example, minimal packaging reduces material use, increases distribution efficiency, and reduces fuel consumption and resulting air emissions. Similarly, building materials can be designed to reduce the overall mass of material needed for a given structure.



The Four R's

The **four R's** (refuse, reduce, reuse, and recycle) are strategies that allow individuals to limit the volume and negative impacts of the waste they generate. They resemble the waste management hierarchy, but focus at the individual scale rather than the scale of a company or waste management system. They are listed in order of most to least environmentally beneficial, and they are all better alternatives than discarding trash into the landfill. Recycling is last because it requires energy to reprocess waste.

To **refuse** is to decline products or processes that harm the environment if you do not need them. Choosing products without packaging is an example of refusing. To **reduce** is to choose products or processes with lower **ecological footprint** (the area of land required to produce them). Examples include products with limited packaging or durable items rather than flimsy or disposable ones. **Reuse** refers to using a product multiple times or finding an alternative use for it. For example, one could share, borrow, or rent items. A plastic yogurt or pudding container could be repurposed for storage or gardening. **Recycling** means to return used items to be reprocessed (figure 13.4.*b*). Commonly recycled materials include cardboard, glass, cans, and certain plastics.

Recycling, as noted above, refers to recovery and reprocessing of useful materials. Numerous examples of successful recycling and reuse efforts are encountered every day. Many construction materials can be reused, including concrete, asphalt materials, masonry, and reinforcing steel. "Green" plant-based wastes are often recovered and immediately reused for mulch or fertilizer applications. Many industries also recover various byproducts for reuse. In some cases, the recycled materials are used as input materials and are heavily processed into end products. Common examples include the use of scrap paper for new paper manufacturing, or the processing of old aluminum cans into new aluminum products. In other cases, reclaimed materials undergo little or no processing prior to their reuse. Some common examples include the use of tree waste as wood chips, or the use of brick and other fixtures into new structural construction. In any case, the success of recycling depends on effective collection and processing of recyclables, markets for reuse, and public acceptance and promotion of recycled products and applications utilizing recycled materials.



Figure 13.4.*b*: Recycling, or returning materials to be reprocessed, is the last of the four R's. If items cannot be refused, reduced, or reused, recycling is a better alternative than discarding into the landfill. Image by Intel Free Press (CC-BY).

Resin identification codes are the triangular symbols on recyclable plastics that indicate their composition (figure 13.4.*c*). A variety of materials make up plastics, and they are not all recycled the same way. Furthermore, your local recycling service may recycle some types of plastics but not others. Plastics with codes 1 and 2 are commonly recycled. For the codes, check with your local recycling service. Local businesses may house collection bins for plastics that are not commonly recycled. For example, grocery stores commonly have receptacles for recycling plastic bags, which fall under code 4.

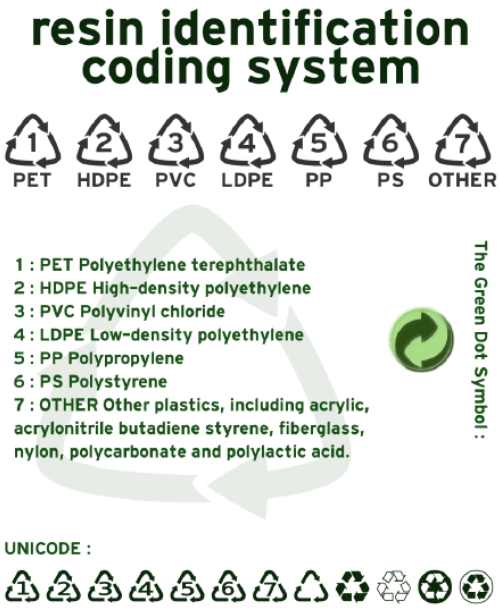
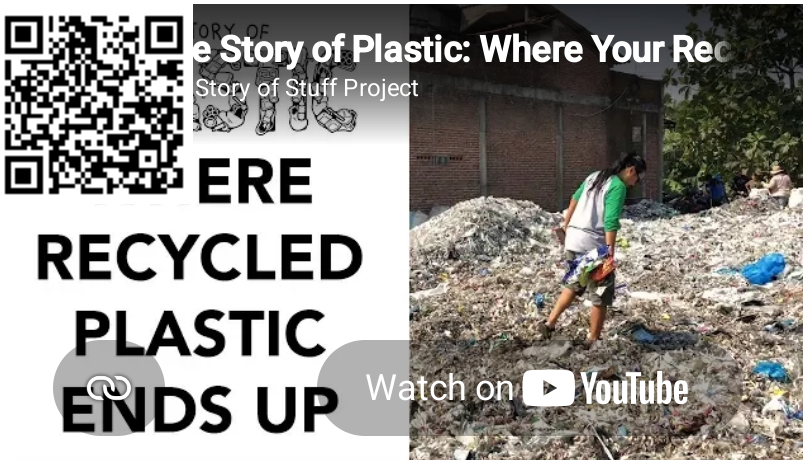


Figure 13.4.*c*): The resin identification coding system explains the chemical composition of various plastics. Some are commonly recycled, and others are not. The text in the image is, "1: PET Polyethylene terephthalate, 2: HDPE High-density polyethylene, 3: PVC Polyvinyl chloride, 4: LDPE Low-density polyethylene, 5: PP Polypropylene, 6: PS Polystyrene, 7: OTHER Other plastics, including acrylic, acrylonitrille butadiene styrene, fiberglass, nylon, polycarbonate and polylactic acid. Image by Filtre/OpenClipart Library (public domain).





Composting

Compost is organic material that can be added to soil to help plants grow (figure 13.4.*d*). Food scraps and yard waste together currently make up more than 30% of what we throw away and could be composted instead. Making compost keeps these materials out of landfills where they take up space and release methane, a potent greenhouse gas that contributes to climate change. Furthermore, compost enriches soil, helping retain moisture and suppress plant diseases and pests. It reduces the need for chemical fertilizers and encourages the production of beneficial bacteria and fungi. Composting can be done at an industrial scale, such as with yard waste collected from homes in a city. It can also be done at home.



Figure 13.4.*d*): Compost is a nutrient-rich substance formed from decomposition of yard and food waste that enriches garden soil. Image by EPA (public domain).

All composting requires three basic ingredients: browns, greens, and water. "Browns" are materials such as dead leaves, branches, and twigs. "Greens" are materials such as grass clippings, vegetable waste, fruit scraps, and coffee grounds. The brown materials provide carbon for your compost, the green materials provide nitrogen, and the water provides moisture to help break down the organic matter. A compost pile should have an equal amount of browns to greens. Layers of these organic materials with different particle sizes should be alternated.



Backyard Composting

Backyard composting requires a compost bin or pile to be placed in dry, shady spot near a water source (figure 13.4.*e*). Brown and green materials are added as they are collected, and larger pieces are chopped or shredded before they are added to the pile. Dry materials are moistened as they are added. Once the compost pile is established, grass clippings and green waste are mixed into the pile when added. When fruit and vegetable wastes are added, they are buried under 10 inches of compost material. Some homeowners cover the top of the compost with a tarp to keep it moist. When the material at the bottom is dark and rich in color, the compost is ready to use. This usually takes anywhere between two months to two years.



Figure 13.4.*e*): This compost bin contains food scraps and yard waste. Image by Ben_Kerckx/Pixabay (Pixabay license)

Indoor Composting

For those who do not have the space for an outdoor compost pile, materials can be composted indoors using a special type of bin, which can be purchased at a local hardware store, gardening supplies store, or made at home. Care must be taken to properly manage the compost pile and keep track of what is added such that it does not attract pests or rodents or smell bad. The compost should be ready in two to five weeks.



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- Systems of Waste Management from *Sustainability: A Comprehensive Foundation* by Tom Theis and Jonathan Tomkin, Editors (CC-BY). Download for free at CNX.
- Composting at Home. Environmental Protection Agency. Accessed 01-18-2021 (public domain).

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13.S: Review

Summary

After completing this chapter you should be able to...

- Distinguish between biodegradable and nondegradable waste.
- Provide examples of hazardous waste.
- List the major waste generating processes globally.
- Compare the volume of waste generated per person per day in the U.S. with other countries around the world.
- Define municipal solid waste and describe its composition in the U.S.
- Compare open dumps, sanitary landfills, and incineration, outlining the advantages and disadvantages of each approach.
- Explain how trash enters the ocean and how it harms marine life.
- Explain the waste management hierarchy.
- List the four R's and provide examples of each.
- Explain the benefits and process of composting.

Solid waste refers to a variety of discarded materials that are deemed useless and discarded by humans. Waste may be easily broken down (**biodegradable**) or **nondegradable**. **Hazardous waste** is harmful to human health. Examples include batteries, cleaners, and **e-waste**. Agriculture, industry, and mining generate most of the world's waste. **Municipal solid waste** (MSW) is discarded from residences, businesses, and city buildings, and the U.S. generates more MSW per person per day than most countries around the world.

Three strategies for disposing of waste are open dumps, sanitary landfills, and incinerators. **Open dumps** cause disease spread, air pollution, and water pollution, and are thus illegal in the U.S. About half of the MSW in the U.S. goes to **sanitary landfills**, which compact trash and seal it to prevent pollution. **Incinerators** burn trash, which reduces its volume while generating energy.

Ocean dumping and escape of trash from overfilled bins and open dumps has contaminated the ocean with many plastics. These break into small pieces and form **garbage patches**. Plastic in the ocean can trap, poison, or otherwise harm marine life.

The **waste management hierarchy** diagrams the priorities of waste reduction. Source reduction and recycling are key to limiting waste and mitigating its environmental impacts. However, a large volume of trash goes to disposal, the least preferred method for handling waste. Individuals can limit their own waste by employing the **four R's**: **refuse**, **reduce**, **reuse**, and **recycle**. **Composting** at home also reduces food and yard waste.

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CHAPTER OVERVIEW

14: Urbanization and Sustainable Cities

14.1: Sustainable Cities

14.2: Revisiting Sustainability

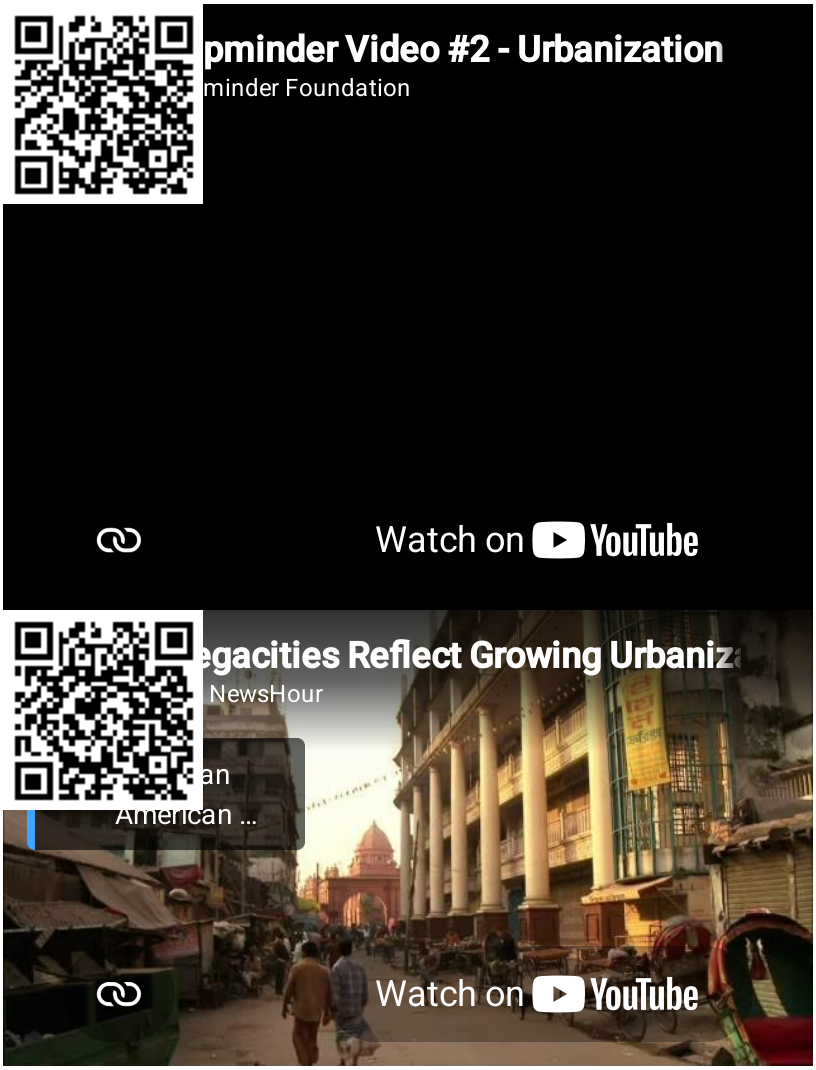
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14.1: Sustainable Cities

Introduction

Sustainability, from science to philosophy to lifestyle, finds expression in the way we shape our cities. Cities are not just a collection of structures, but rather groups of people living different lifestyles together. When we ask if a lifestyle is sustainable, we're asking if it can endure. Some archaeologists posit that environmental imbalance doomed many failed ancient civilizations. What could the sustainable city look like, how would it function, and how can we avoid an imbalance that will lead to the collapse of our material civilization? While attempting to envision the "sustainable city" we must discern what factors will influence its shape and form in the future.

The History of Cities and Urbanization



So what is the major hindrance for designing/updating for a "sustainable city"?

Sprawl: The outward expansion of human populations (typically in low-density residential and commercial development) into the outer edges of cities/towns.

As sprawl expands, it eats at natural and agricultural lands and isolates people. People have to travel further and further to go to work, the grocery store, a hospital, etcetera. What this means is that cities/towns have to find solutions to moving water, waste, power, services, road development/upkeep, etcetera to these communities. As such, there are chronic issues with sprawl on both sides that make opportunity and progress difficult due to economic constraints.

It's important to note that sprawl can happen at different scales:

- **Low-density sprawl:** Small 1-2 story buildings in high densities. Low-density sprawl can be further distinguished by income as neighborhoods tend to be segregated by this. (Ex: North America)
- **High-density sprawl:** High rise buildings in high densities (Ex: China)



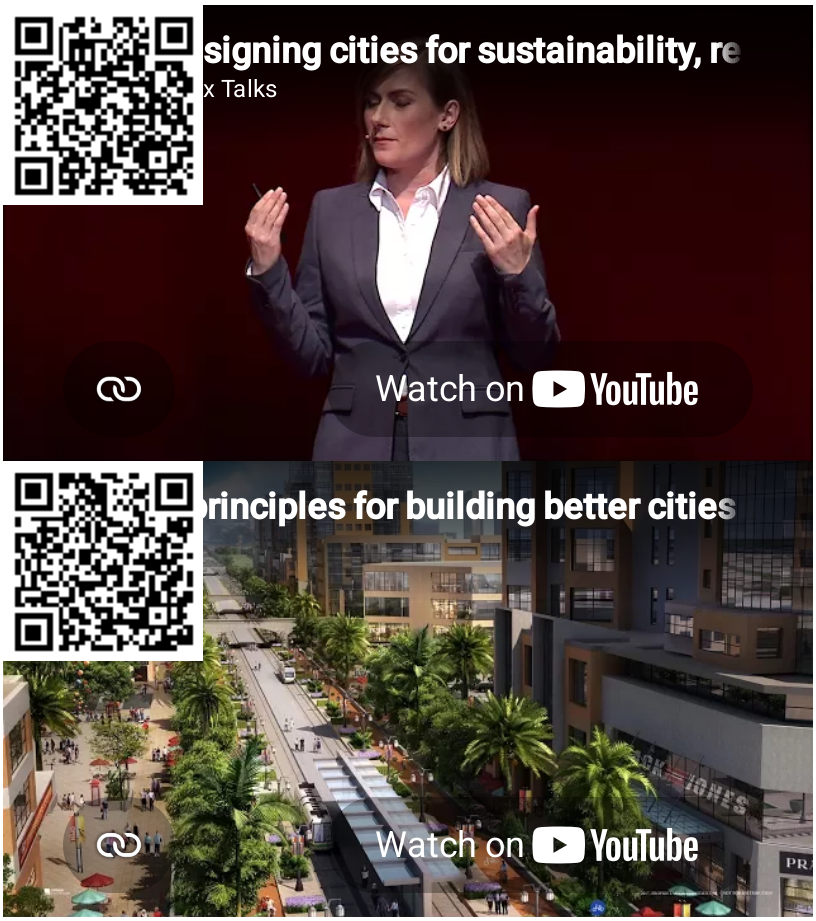
Figure 14.1.*a*: Left - High density sprawl in Shanghai China by John Patrick Robichaud in Wikimedia Commons (CC-BY), Right - Low density sprawl in North America by Pixnio (Public Domain).

So what can be done to design/update and move towards "sustainable cities"?

- **Mixed use development:** Lends residential, commercial, cultural, institutional, or industrial uses, where those functions are physically and functionally integrated, and that provides pedestrian connections. Making cities walkable!
- **Geographic equity:** Circulation system defined by ratios of how people move. This means more bikes, walking, public transportation (in many forms) and not cars. Equitability of the streets!
- **Preserve:** Preserve land, culture, and biodiversity as much as possible.
- **Mix**: Mix incomes, cultures, green spaces, public transport options, etcetera as much as possible. Allow people to connect and become neighbors not strangers.
- **Focus:** Match density of a community to meet transit/service needs.

New Urbanism vs Suburbanism





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14.2: Revisiting Sustainability



Cities in today's modern world are struggling to balance a sustainable society, economy, and environment. According to a 2016 report that rated sustainability across 32 indicators, Zurich, Switzerland, was ranked number one. Zurich invests in renewable energies, sustainable public transport, public green space, and public education. One of the most notable ways Zurich is leading global sustainability efforts is its dedication to keeping its carbon dioxide emissions low (Figure 14.2.*a*.

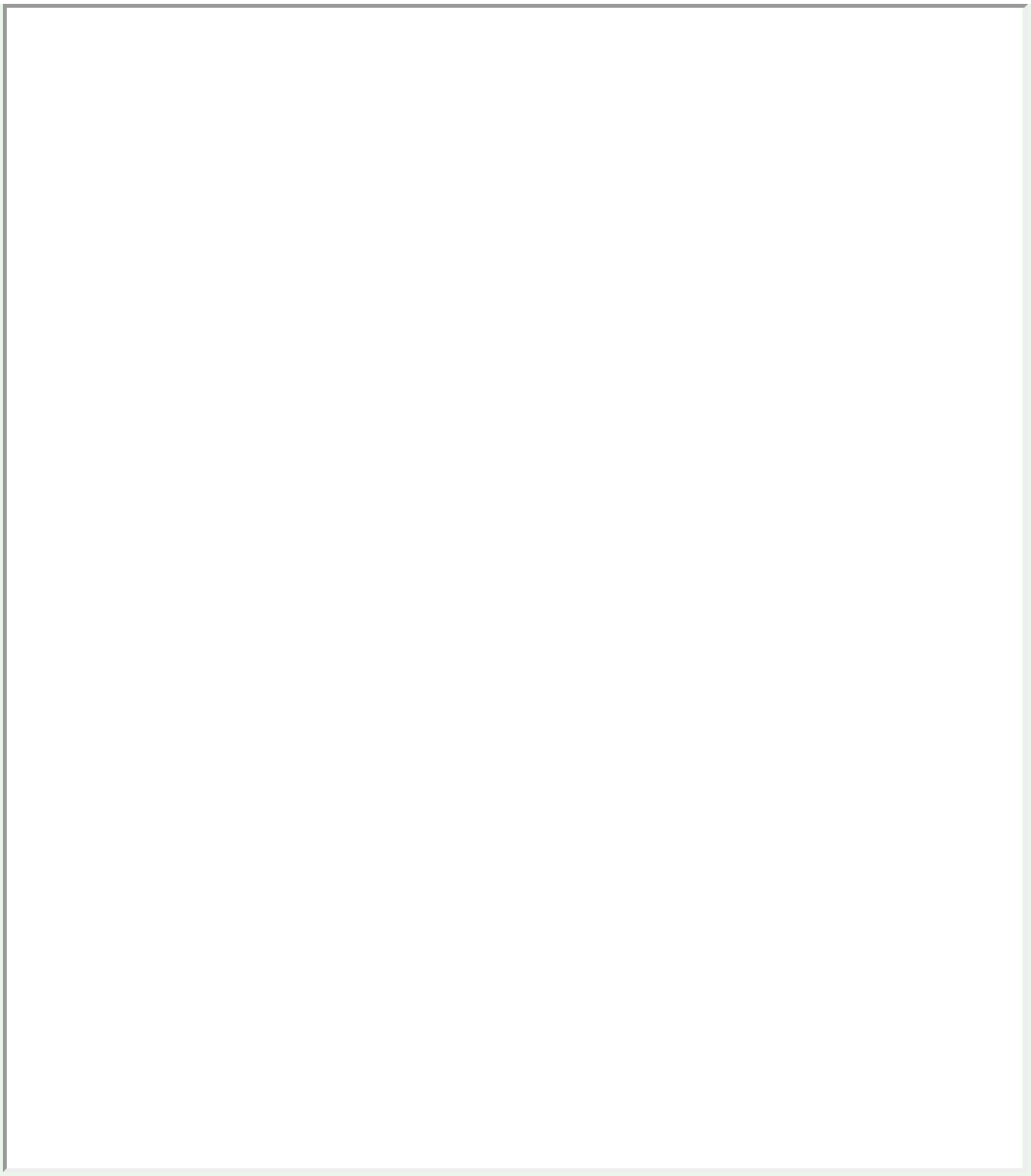


Figure 14.2.*a*: Per capita emissions of carbon dioxide between the United States and Switzerland. Graph by Our World in Data (CC-BY4.0)

Introduction

Sustainability is derived from two Latin words: *sus*, which means up, and *tenere*, which means to hold. Thus, sustainability is essentially about sustaining human existence by meeting the needs of the present without compromising the ability of future generations to meet their own needs.

There are three dimensions that sustainability seeks to integrate: economic, environmental, and social (including sociopolitical).

- Economic interests define the framework for making decisions, the flow of financial capital, and the facilitation of commerce, including the knowledge, skills, competencies, and other attributes embodied in individuals that are relevant to economic activity.
- Environmental aspects recognize the diversity and interdependence within living systems, the goods and services produced by the world's ecosystems, and the impacts of human wastes.

- Social/Socio-political refers to interactions between institutions/firms and people; functions that express human values, aspirations, and well-being; ethical issues; and decision-making that depends on collective action.

The intersection of social and economic elements can form the basis of social "equitability". In enlightened management, "viability" considers both economic and environmental interests. Between the environmental and social elements lies “bearability,” the recognition that the functioning of societies is dependent on environmental resources and services. At the intersection of all three of these lies sustainability (figure 14.2.*b*).

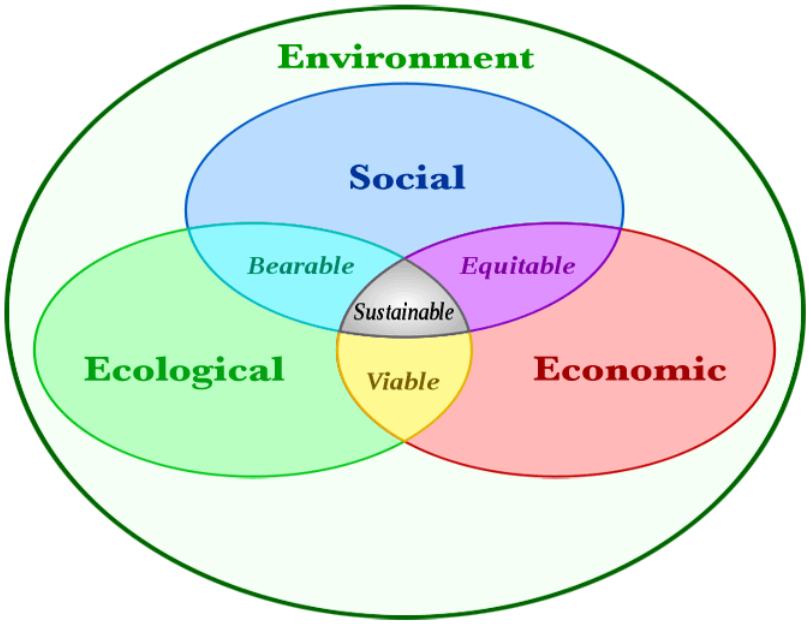


Figure 14.2.*b*: Venn diagram of defining the components of sustainability. Image by Andrew, Sunray, based on "File:Sustainable development.svg" by Johann Dréo in Wikimedia Commons (CC-BY-SA4.0)

The three main elements of the sustainability paradigm are equally important; however, tradeoffs occur depending on the local/global objective. For example, in some instances, it may be deemed necessary to degrade a particular ecosystem to facilitate commerce, food production, or housing. In reality, the extent to which tradeoffs are made before irreversible damage occurs is not always known. In any case, there are definite limits on how much substitution among the three elements is wise (to date, humans have treated economic development as the dominant one of the three).

This has led to the notion of **strong sustainability**, where tradeoffs among natural, human, and social capital are not allowed or are very restricted, or **weak sustainability**, where tradeoffs are unrestricted or have few limits.

Whether or not one follows the strong or weak form of sustainability, it is important to understand that while economic and social systems are human creations, the environment is not. Rather, a functioning environment underpins both society and the economy.



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CHAPTER OVERVIEW

15: Our Environmental Future

Learning Objectives

- Define sustainability and the sustainability paradigm
- Describe the historical development of the sustainability paradigm
- Describe how ethics and moral extensionism connect to sustainability
- Understand that true sustainability promotes environmental equity and justice, thus eliminating environmental racism
- Describe the evolution of ethics leading to the modern environmental ethic
- Understand how environmental policy has changed based on movements and need
- Describe how sustainable lifestyle choices influence sustainability

Video



In this 7-minute animated video, a simple definition of sustainability is presented based on science and natural cycles, in addition to the four root causes of un-sustainability (the 4 things we need to stop doing in order to become sustainable).

Question after watching: Which of these concepts are review from the previous 5 Units? Which are new?

15.1: Revisiting Sustainability
15.2: History of Sustainability
15.3: Revisiting Environmental Ethics and Justice
15.4: Ecological Economics
15.5: Environmental Policy
15.6: Sustainability and the Future
15.S: Summary
5.4.1: Introduction to Sustainability
5.4.2: Sustainability Ethics and Environmental Justice
5.4.3: Environmental Policy, Monitoring, and Impact Assessments
5.4.4: Sustainability and the Future

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15.1: Revisiting Sustainability



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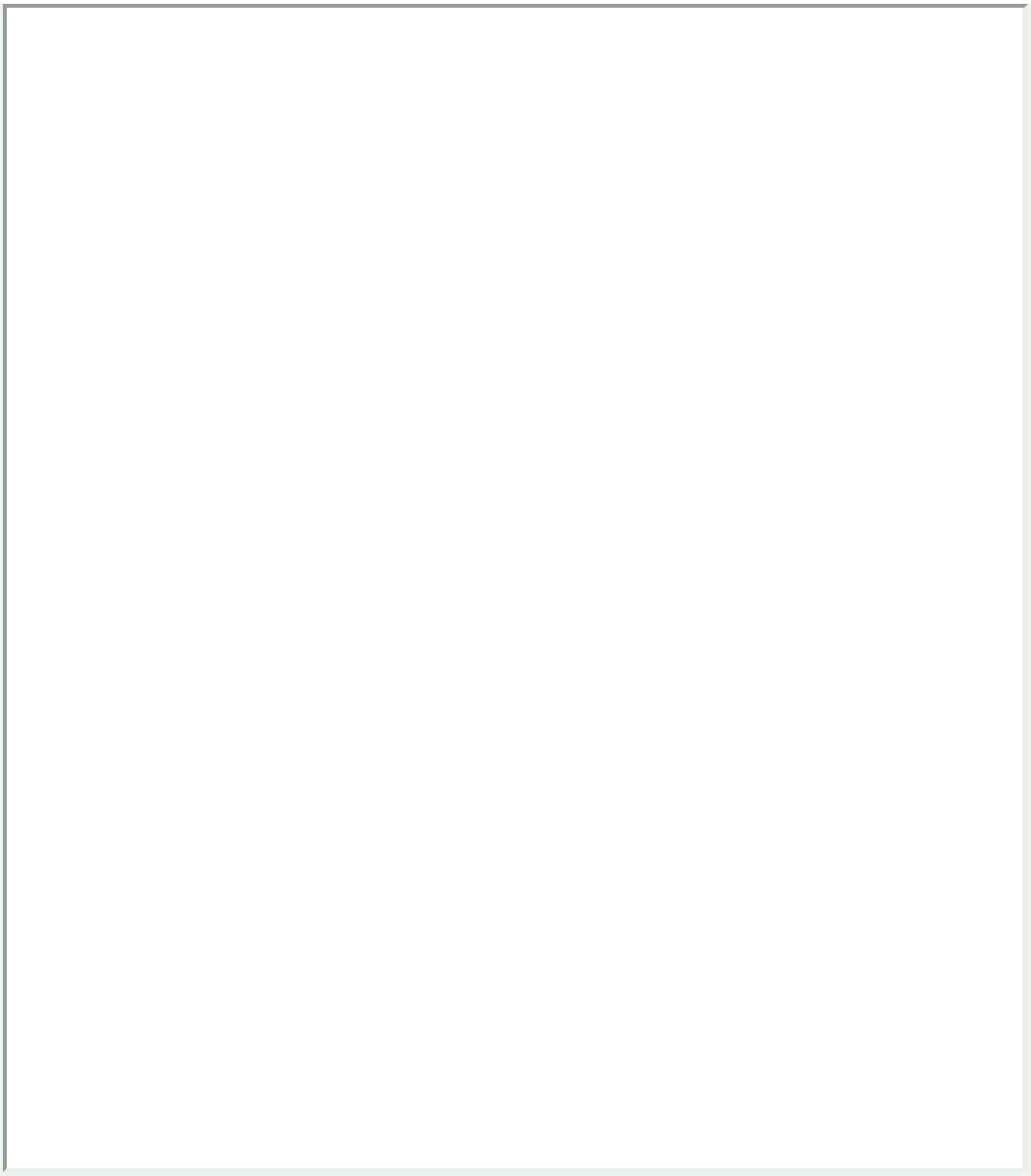


Figure 15.1.*a*: Per capita emissions of carbon dioxide between the United States and Switzerland. Graph by Our World in Data (CC-BY4.0)

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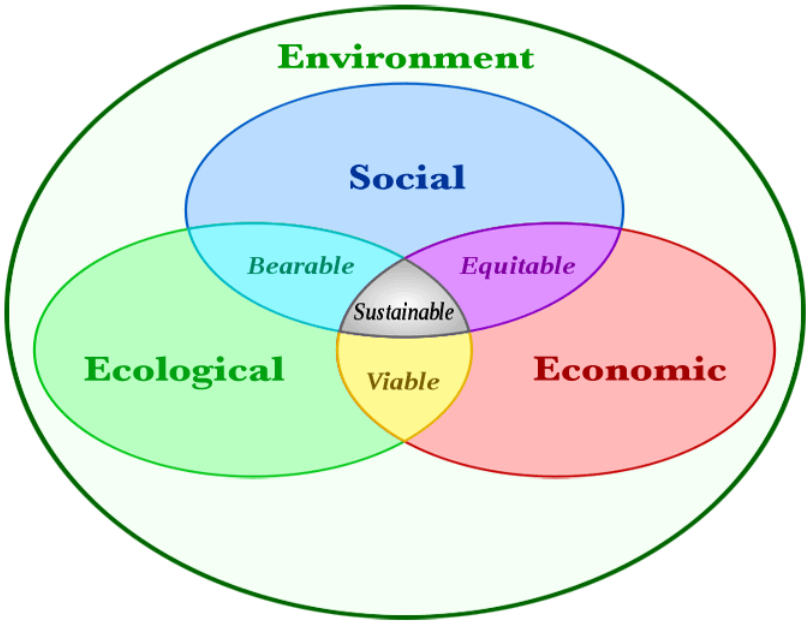


Figure 15.1.*b*: Venn diagram of defining the components of sustainability. Image by Andrew, Sunray, based on "File:Sustainable development.svg" by Johann Dréo in Wikimedia Commons (CC-BY-SA4.0)

The three main elements of the sustainability paradigm are equally important; however, tradeoffs occur depending on the local/global objective. For example, in some instances, it may be deemed necessary to degrade a particular ecosystem to facilitate commerce, food production, or housing. In reality, the extent to which tradeoffs are made before irreversible damage occurs is not always known. In any case, there are definite limits on how much substitution among the three elements is wise (to date, humans have treated economic development as the dominant one of the three).

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15.2: History of Sustainability

Taking The Long View: Sustainability an 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:

1. 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.
2. 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 be 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.
3. 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…

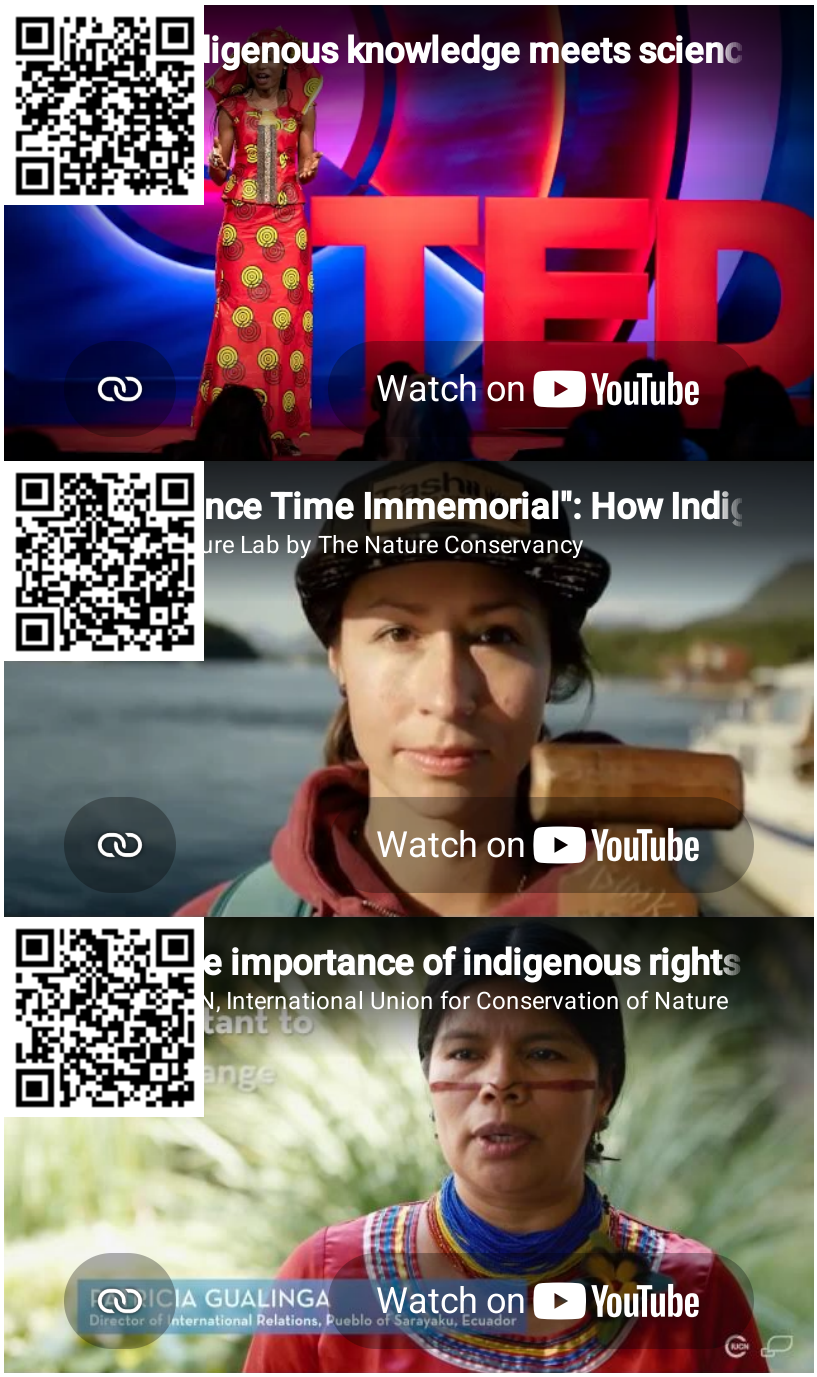
- …development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- … sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the orientation of the technological development,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



Figure 15.2.*a*: Cover of Our Common Future. Image by Sigurður Kaiser in Wikimedia Commons (CC-BY-SA4.0)

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.





Precautionary Principle

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.

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SECTION OVERVIEW

15.3: Revisiting Environmental Ethics and Justice

Introduction

Ethics involves standards of conduct. These standards help to distinguish between behavior that is considered right and that which is considered wrong. It is not always easy to distinguish right from wrong, as there is no universal code of ethics.

For example, a poor farmer clears the rainforest to grow crops. Some would not oppose this action, because it allows the farmer to provide food and income for his family. Others would oppose the action, claiming that the deforestation will contribute to soil erosion and global warming. An individual's **morals** usually determine their sense of right and wrong.

To change the ethics of an entire society, it is necessary to change the individual ethics of a majority of individuals.

Moral extensionism defines how far a person's values extend outside of themselves (Figure 7.2a). Many variables can influence where the limit lies for each person. For example: religion, culture, education, and personal interests.

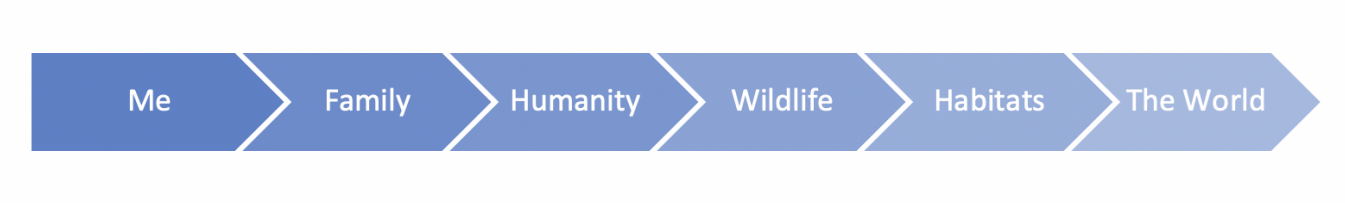


Figure 15.3.*a***:** Scope of consideration for moral extensionism. Rachel Schleiger, CC-BY-NC.

Environmental Equity

Environmental equity describes a country, or world, in which no single group or community faces disadvantages in dealing with environmental hazards, disasters, or pollution. While much progress has been made to improve resource efficiency, far less has been made to improve resource distribution. Currently, just one-fifth of the global population is consuming three-quarters of the earth's resources.

Global Consumption Inequality - 24% of the global population (mostly in high-income countries) accounts for...

- 92% Cars
- 70% Carbon dioxide emissions
- 86% Copper and aluminum
- 81% Paper
- 80% Iron and steel
- 48% Cereal crops
- 60% Artificial fertilizer

If the remaining three-quarters 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 resource consumption/waste emissions) of industrialized countries.

Countries such as China, Brazil, India, and Malaysia are catching up fast, however. In such a situation, global consumption of resources and energy needs to be drastically reduced so that future generations also have access.

But who will do the reducing? Poorer nations want to produce and consume more. Yet so do richer countries: their economies demand more and more consumption. Such stalemates have prevented any meaningful progress towards equitable and sustainable resource distribution at the international level. These issues of fairness and distributional justice remain unresolved.

Environmental Justice

Environmental Justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income in 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.

In Flint, Michigan, the city decided to save money by drawing water for residents from the Flint River in 2014. Residents complained about the taste, smell, and color of the water (Figure 15.3.a). Scientific studies found that failure to apply corrosion inhibitors to the water resulted in lead from aging pipes to leach into the water supply, exposing around 100,000 residents to elevated lead levels. Although the city switched back to its original water source, the damage was already done. Not only did this crisis expose many to lead, which is especially concerning for children, but most pipes needed to be replaced since they were no longer safe to use. In 2017, a settlement was reached to replace all the pipes, a $87 million project. However, as of Jan 2021, this project was only beginning to approach completion. Citywide lead levels have tested within the safe range for consumption, though houses considered high risk do continue to show elevated levels.



Figure 15.3.a: Flint residents trying to bring awareness of the Flint Water Crisis through peaceful demonstration. Image by Shannon Nobles in Wikimedia Commons (CC-BY-SA-4.0).

During the 1980's, underserved groups protested that hazardous waste sites were preferentially sited in minority neighborhoods. In 1987, **environmental racism** was coined 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 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 but the long-term consequences are unknown.

In an ideal world, there would be no hazardous wastes to plague this planet. Unfortunately, we live in a world with rampant pollution, dumping of hazardous wastes, and people with "living for the now" attitudes. Our industrialized society has necessarily produced waste 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 (Figure b). 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 15.3.*b***:** Bernadette Demietieff speaking in support of protect the Arctic to protect Gwich'in land from oil drilling, Alaska, c. 2019. Image by: Deb Haaland in Wikimedia Commons (CC-BY-SA-4.0).

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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Topic hierarchy

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15.4: Ecological Economics

INTRODUCTION

Economics is the process by which humans manage their environment and its resources. The process is made up of a system of production, distribution and consumption of goods and services. **Natural resources** provide the raw materials and energy for producing economic goods, while **human resources** provide the necessary skill and labor to carry out the process. Different societies manage their economies in different ways. In a traditional economy, people are self-sufficient (i.e., they produce their own goods), but in a **pure command economy** the government controls all steps in the economic process.

Capitalist countries such as the United States have a system that is largely based on a **pure market economy**. Buyers and sellers make economic decisions based on the **Principle of Supply and Demand**. Sellers supply goods and buyers create demand for goods. These two roles are often in conflict: buyers want to buy goods at low prices and sellers want to sell goods at high prices. However, the two sides eventually compromise on a price at which buyers can find sellers willing to sell and sellers can find buyers willing to buy. This is known as the **market equilibrium price**. The equilibrium price can be considered as the intersection of the supply and demand curves.

Most countries strive to increase their capacities to produce goods and services and consider doing so as a positive sign of development. Economic growth is stimulated by population growth, which in turn increases the consumption of natural resources and increases the per capita consumption of goods and services. Various indicators are used to measure economic growth. One of them is the **Gross National Product (GNP)**, which represents the total market value of final goods and services produced by a country during a given period (usually one year). Unfortunately, GNP does not take into account the global nature of many companies. If a company produces goods in a foreign country, then the "home" country does not really benefit from that production. Thus, if Pepsi bottles and sells soda in Japan, those revenues should not be included in the GNP of the United States. The **GDP (Gross Domestic Product**) provides a better indicator of the health of a country's economy. This measure refers to the value of the goods and services produced within the boundaries of an economy during a given period of time.

Both the GNP and Gross Domestic Product (GDP) are economic measures and indicate nothing about social or environmental conditions within a country. They are not measures of the quality of life. In fact, severe environmental problems can actually raise the GNP and GDP, because the funds used to clean up environmental messes (such as hazardous waste sites) help to create new jobs and increase the consumption of natural resources. The **United Nations Human Development Index** is an estimate of the quality of life in a country based on three indicators: life expectancy, literacy rate and per capita GNP.



EXTERNAL COSTS [Externalities]



Economic activity generally affects the environment, usually negatively. Natural resources are used, and large amounts of waste are produced. These side effects can be seen as ways in which the actions of a producer impact the well being of a bystander. The market fails to allocate adequate resources to address such external costs because it is only concerned with buyers and sellers, not with the well being of the environment. Only direct (or internal) costs are considered relevant. External costs are harmful social or environmental effects caused by the production or consumption of economic goods. Governments may take action to help alleviate the effects of economic activity.

When external costs occur, a company's private production cost and the social cost of production are at odds. The firm does not consider the cost of pollution cleanup to be relevant, while society does. The social costs of production include the negative effects of pollution and the cost of treatment. As a result, the social costs end up exceeding the private production costs. When external pollution and treatment costs are included in the production cost of the product, the supply curve intersects the demand curve at a higher price point. As a result of the higher price there will be less demand for the product and less pollution produced.

For example, exhaust pollutants from automobiles adversely affect the health and welfare of the human population. However, oil companies consider their cost of producing gasoline to include only their exploration and production costs. Therefore, any measures to reduce exhaust pollutants represent an external cost. The government tries to help reduce the problem of exhaust pollutants by setting emissions and fuel-efficiency standards for automobiles. It also collects a gasoline tax that increases the final price of gasoline, which may encourage people to drive less.

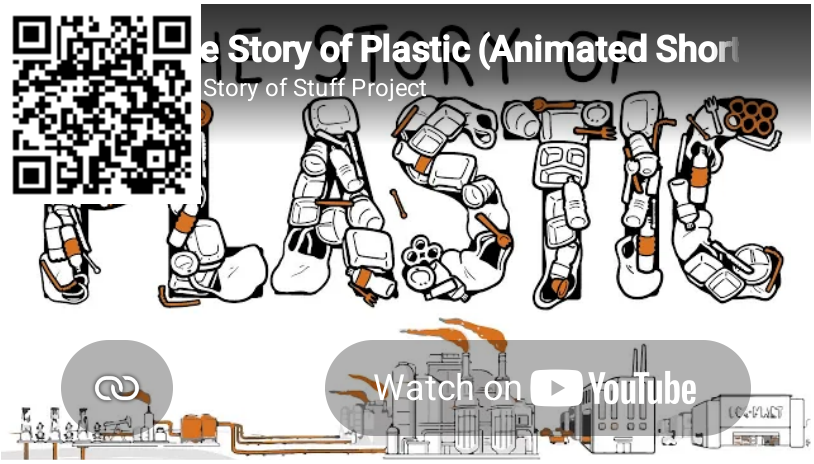
Sometimes, pollution results from the production process because no property rights are involved. For example, if a paper manufacturer dumps waste in a privately owned pond, the landowner generally takes legal action against the paper firm, claiming compensation for a specific loss in property value caused by the industrial pollution. In contrast, the air and most waterways are not owned by individuals or businesses, but instead are considered to be public goods. Because no property rights are involved the generation of pollution does not affect supply and demand.

Firms have an incentive to use public goods in the production process because doing so does not cost anything. If the paper manufacturer can minimize production costs by dumping wastes for free into the local river then it will do so. The consequences of this pollution include adverse impacts on the fish and animal populations that depend on the water, degradation of the surrounding environment, decrease in the quality of water used in recreation and business, human health problems and the need for extensive treatment of drinking water by downstream communities. An important role of the government is to protect public goods, especially those with multiple uses, from pollution by companies seeking to minimize company costs and to maximize profits. People desire clean water for recreation and drinking, and the government must act to protect the broad interests of society from the narrow profit-driven focus of companies.

One way to "internalize" some of the external costs of pollution is for the government to tax pollution. A pollution tax would require that polluting firms pay a tax based on the air, water and land pollution that they generate. This tax would raise the private production cost of a company to include to the social cost of production. In addition, the generated tax revenues could be used by the government to help mitigate the effects of pollution. The main drawback of such a tax is that it would discourage economic activity by increasing costs to the companies. For example, a tax on coal and oil would increase the cost of electricity and gasoline.

Taxed companies would be forced to scale back production in response to these higher costs, and investments and employment would suffer. The trick is to set the tax at a level at which economic loss does not exceed the environmental benefits realized.

Tradable Pollution Permits (TPPs) are an alternative to pollution taxes. In 1994, the United States government inaugurated a program to reduce sulfur dioxide emissions by requiring that companies have a permit for each ton of sulfur dioxide they emit. Companies were allocated TPPs based on their historical level of sulfur dioxide emissions. The program allows TPPs to be bought and sold among the companies. Therefore, a company can invest in scrubbers or use more expensive low sulfur coal to reduce its sulfur dioxide emissions and then sell its excess permits, offsetting part of the cost of reducing the pollution.



COST-BENEFIT ANALYSES

Ideally, one would like to live in a perfect world with zero pollution. Unfortunately, this is not possible with current technology. People drive cars and trucks, and most of these vehicles have internal combustion engines, which emit pollutants. Unless gasoline or diesel powered vehicles are completely banned, that pollution will persist. However, a few electric vehicles are starting to appear on the road, although they are impractical for long distance use or heavy hauling. Obviously, most people are not going to give up their internal combustion engine vehicles in the near future. People generally accept that some pollution is a result of living in a modern society. The critical issue, then, is how much pollution control is economically practical. A cost-benefit analysis provides an estimate of the most economically efficient level of pollution reduction that is practical.

A **cost-benefit analysis** looks at the social benefits (e.g., health and environmental benefits) that can be derived from pollution reduction versus the cost of achieving that reduction. As the pollution reduction increases, so does the money required to reduce pollution further. It may not be very expensive to clean up the bulk of most pollutants. However, as the reduction in pollutants approaches 100 percent (i.e., zero emissions), the marginal cost of each additional unit of pollution reduction rises dramatically. If public funds are used for pollution control, there is a limit to how much money can be spent before the budgets of other important public services (e.g., police, fire and parks departments) are negatively impacted. A balance must therefore be found between the social benefits of pollution reduction and the cost of pollution reduction. The proper balance between costs and benefits represents the optimum economic level of pollution reduction.

The optimum level is not static, but can change as circumstances change. As technology improves over time, the cost of pollution reduction may decrease. Likewise, as the hazards of pollution become better known, the perceived benefits to be derived from pollution reduction may also increase. In either case, the optimum level of pollution reduction will then increase and a greater level of pollution reduction will be considered economically feasible. The eco-efficiency program at the 3M Corporation is an example of how the optimum level of pollution reduction can be raised through better management and design of manufacturing processes. Over the time period 1990 to 2000, the company reduced its air pollution by 88 percent, water pollution by 82 percent and waste generation by 35 percent.

One problem with using cost-benefit analyses for determining the optimum level of pollution reduction is that it assumes all benefits can be labeled with a price tag. However, aesthetic benefits from pollution reduction cannot be priced, and yet they are just as important as others. The beauty of a clear-running stream and the quiet solitude of a wilderness area cannot be measured in dollars and cents.





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15.5: Environmental Policy

Introduction

It is not uncommon to think of the sustainability paradigm as being a recent interpretation of environmental policy, one that was given credence by the United Nations report "Our Common Future" (the Brundtland Report) when it was first presented in 1987. However, it would be a mistake to conclude that sustainability as a mental construct and policy framework for envisioning the relationship of humans and nature came into being suddenly and at a single moment in time. Most environmental historians who have studied U.S. policy have discerned at least three distinct periods during which new concepts and ideas, scientific understandings, technological advances, political institutions, and laws and regulations came or were brought into being in order to understand and manage human impacts on the environment.

1. **The American conservation movement:** This 19th century movement had the main objective for conservation of American land and resources, it grew from opposite philosophies. On one side you had people like Gifford Pinchot (first head of the US National Forest Service) that were very pragmatic about their desire for conservation. For example, these people observed that policies for harvesting some resource (like lumber) were not sustainable, so they began conservation/sustainability research and new policies so the resource would not run out in the foreseeable future. On the other side were people like John Muir and Theodore Roosevelt that saw land/habitats/wildlife as intrinsic entities, meaning that had value in their own right (meaning nothing to do with money).
2. **The rise of environmental risk management as a basis for policy:** The beginnings of environmental risk management can be traced to the fields of public health, industrial hygiene, and sanitary engineering, which came into prominence in the latter decades of the 19th century and beginning of the 20th. The spread of disease was a particularly troublesome problem as the country continued to urbanize. In addition, environmental scientists of the day were alarmed by the extent and degree of damage that they were documenting. The publication of *Silent Spring* in 1962 by Rachel Carson (1907-1964), about the impact of the widespread and indiscriminate use of pesticides, was a watershed moment, bringing environmental concerns before a large portion of the American, and global, public. Carson, collected scientifically documented evidence on the effects of pesticides, particularly DDT, heptachlor, and dieldrin, on humans and mammals, and the systemic disruption they caused to ecosystems. *Silent Spring* is credited with bringing about a ban on the use of DDT in the United States, and setting in motion a chain of events that would ultimately result in the transformation of environmental public policy from one based on the problems and attitudes that brought about nineteenth century conservation, to one based on the management of risks from chemical toxins. The U.S. Environmental Protection Agency was established in 1970, just eight years after the publication of *Silent Spring*. The same year Earth Day was created.
3. **The integration of social and economic factors to create what we now refer to as the sustainability paradigm:** Eventually, we (humanity) realized that in order to solve environmental issues (like ones identified by Rachel Carson), that the "human factors" (both social and economical) had to be accounted for. This is what defines the sustainability paradigm: environmental, social, and economic disciplines. Only Band-Aid solutions can be applied if we only take a one-minded approach.



History of Environmental Policy

Environmental policies are typically driven by problems of the day, real and perceived, that require systemic solutions. For example:

- Early conservationists were alarmed at the inefficiencies of human resource management and the encroachment of humans on unspoiled lands... Leading to conservation legislation.
- During the 20th century many groups (scientists, economists, politicians, and ordinary citizens) became alarmed and fearful of the consequences of toxic pollutant loads to the environment that included localized effects on human health and well-being... Leading to clean air and water legislation.
- As we proceed into the 21st century, an array of complex problems that have the potential to alter substantially the structure and well-being of large segments of human societies, calls for a renewal and reassessment of our approach to environmental policy.

This has, thus far, proven to be a difficult transition. Many of these complex problems have multiple causes and impacts, affect some groups of people more than others, are economically demanding, and are often not as visibly apparent to casual observers as previous impacts, nor are the benefits perceived to be commensurate with costs. Devising a regulatory strategy for such problems requires an adaptive and flexible approach that current laws do not foster.

Table 15.5.*a***:** Table illustrating evolution of environmental policy. Table by Sustainability: A Comprehensive Foundation in Openstax (CC-BY).

	1850-1920	1960-1990	1990-Present
Focus	Conservation/sanitation	Media/site/problem specific	Complex regional/ global problems
Outcome	Land preservation/efficiency/control of disease	Manage anthropocentric and ecological risk	Global sustainable development
Principal Activity	Resource management reform/simple contaminant controls	Compliance/remediation/technological emphasis on problem solving	Integration of social, economic, and technological information for holistic problem solving
Economic Focus	Profit maximization/public health	Cost minimization	Strategic investments/long-term societal well-being
Regulatory Activity	Low	Heavy	Adaptive and flexible
Conceptual Model	Expansion vs preservation	Command and control	Systems/life cycle approach
Disciplinary Approach	Disciplinary and insular	Multidisciplinary	Interdisciplinary/integrative

Table 15.5.*b***:** Table illustrating major environmental legislation, society, and organization conceptions. Table by Rachel Schleiger (CC-BY-NC).

Year	Policy/Society/Organization Conception
1899	Refuse Act
1905	National Forest Service
1916	National Park Service
1918	Migratory Bird Treaty Act
1930's	State Parks
1948	Federal Water Pollution Control Act
1950	The Nature Conservancy
1955	Air Pollution Control Act
1961	World Wildlife Federation
1963	Clean Air Act (1970, 1977, 1990 updates)
1965	Solid Waste Disposal Act (1976 update)
1965	Water Quality Act (1987 update)
1967	Air Quality Act
1969	National Environmental Policy Act
1970	Occupational Safety and Health Act
1970	Environmental Protection Agency
1971	Occupational Safety and Health Administration
1972	Consumer Product Safety Act
1972	Federal Insecticide, Fungicide, and Rodenticide Act
1972	Clean Water Act (1977 update)
1972	Noise Control Act
1973	Endangered Species Act
1974	Safe Drinking Water Act (1986, 1996 updates)
1975	Hazardous Materials Transportation Act
1976	Resource Conservation and Recovery Act
1976	Toxic Substances Control Act
1980	CERCLA (Superfund)
1984	Hazardous and Solid Waste Amendments
1986	Superfund Amendments and Reauthorization Act
1986	Emergency Wetlands Resources Act
1990	Oil Pollution Act
1993	North American Free Trade Agreement
2003	Healthy Forest Initiative



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15.6: Sustainability and the Future

Ecological Footprint

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.

Common Cause and Sustainability

Common cause: Brings about change in all people/interest groups/world leaders because of common goals. Below are a list of sustainability goals across the sustainability paradigm. Most, if not all, are common cause goals for the now, and into the future.

Society

- No poverty
- Zero hunger
- Good health
- Quality education
- Gender equality
- Peace, justice, and strong institutions
- Clean water and sanitation
- Reduced inequalities

Environment

- Terrestrial life/habitats conservation and restoration
- Oceanic life/habitats conservation and restoration
- Climate action
- Reduced waste/pollution

Economy

- Affordable and clean energy
- Decent work and economic growth
- Industry, innovation, and infrastructure
- Responsible consumption and production
- Sustainable cities and communities
- Partnerships locally and globally

Sustainable Living

Sustainable living describes a lifestyle that attempts to reduce/eliminate an individuals (or societies) use of resources so as to be as close as possible to "net zero living". As such, an individual (or society) focuses on reducing their footprint (ecologically, carbon, socially, etc) through their choices/methods of:

- Use of resources (energy/diet/transportation/water/etc)
- Support of people/companies (voting/economic/social/etc)
- Practices of reducing, reusing, and recycling
- Consciousness of priority and focus for local concerns/needs versus global concerns/needs
- Sharing knowledge with their community (all ages)

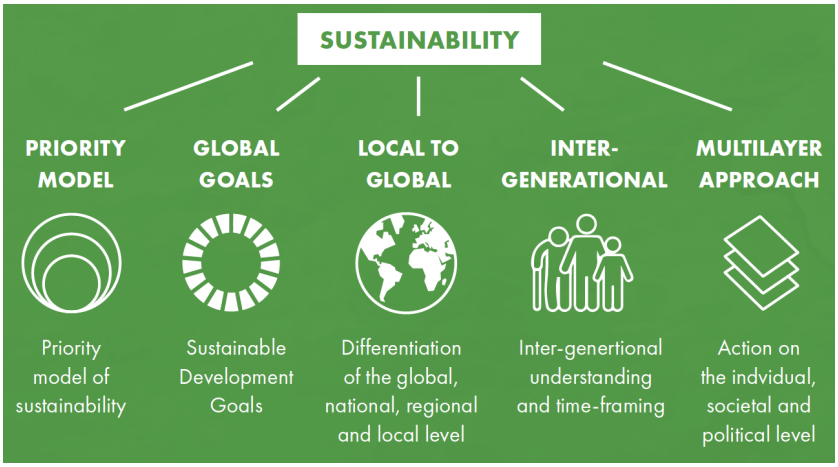


Figure 15.6.*a*: Considerations for sustainable living goals. Image by Sustainability Week Switzerland in Wikimedia Commons (CC-BY-SA)

The thought of getting started with sustainable living can be overwhelming! However, it is important to note that although we can acknowledge all the things that need to be accomplished, that that entire burden does not lie with just one individuals control (see figure below). It takes a multi-layerd approach to appropriately take action at the individual, societal, and political levels (see figure above).

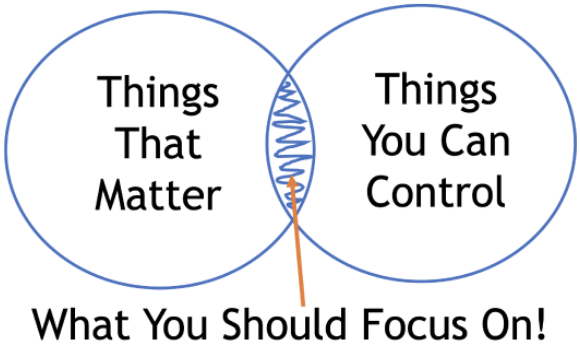


Figure 15.6.*b*: Focus for individual sustainability lifestyle goals. Image by Rachel Schleiger (CC-BY-NC)

The Bionic World

This book will conclude by stating a huge myth held by most of today's society, the myth of the **Bionic World**. It is the belief that science and technology will solve the pressing issues of human's impact on this earth. If society follows this logic, we have no tough choices to make about how we view and treat our surroundings, and decisions can be put off until the economic markets demand or justify a solution. Society can hope to be right…. However, until supporting evidence emerges that humanity can solve all their own problems with the ever shrinking timeline to do so, then we need to start making tough choices to ensure an equitable and sustainable future.



Figure 15.6.c: Robot arm holding up the Earth. Image by Pixabay (Public Domain)



Video 15.6.a**:** Perspectives: Michael Green discusses sustainability goals and what we can do moving forward (Videos from 2015 and 2018)





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15.S: Summary

Summary

After completing this chapter you should be able to...

- Define sustainability and the sustainability paradigm
- Describe the historic events that lead to the sustainability paradigm
- Describe how ethics and moral extensionism connect to sustainability
- Understand that true sustainability promotes environmental equity and justice, thus eliminating environmental racism
- Describe the evolution of ethics leading to the modern environmental ethic
- Understand how environmental policy has changed based on movements and need in the US
- Define what sustainable cities are
- Describe how sprawl is a hindrance to sustainable cities
- Describe how sustainable lifestyle choices influence sustainability
- Acknowledge that the Bionic World is a myth

Sustainability is focused on meeting current needs without compromising the future generations to meet theirs. Sustainability is a paradigm created out of necessity from our past negligence to society, ecology, and economy (the three main components of sustainability).

Ethics plays a large role in addressing current and future sustainability goals necessitated from historic action/inaction. This is especially true for matters of **environmental justice and racism**, in addition to **environmental policies** and movements.

Sustainable cities are also discussed to address the large-scale sustainability concerns of how humanity lives. **Sprawl** is the biggest hindrance for creating the sustainable city. There are two main types of sprawl, **low-density** and **high-density**, that can be observed in many differently populated city layouts.

The **ecological footprint** is a tool to help illustrate the imbalance between lifestyles and behaviors and what is ecologically sustainable. In order to decrease ecological footprints, in addition to environmental injustices, sustainability promotes **common cause** sustainability goals. These emphasize that most goals humanity have are the same, and that these should be what both motivate and unite us as we move towards an uncertain future. In addition, humanity should also consider how we are approaching meeting these goals. The **myth of the bionic world** warns us not to make assumptions or take the easy way out. Only through tough decisions can we ensure an equitable and sustainable future.

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Unit 5.4.1 - Introduction to Sustainability

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 2 hours.
- Optional Activities are embedded.
- Bolded terms are located at the end of the unit in the Glossary. There is also a Unit Summary at the end of the Unit.
- To navigate to Unit 5.4.2, use the Contents menu at the top of the page OR the right arrow on the side of the page.
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Learning Objectives

- Define sustainability and the sustainability paradigm
- Describe the historic events that lead to the sustainability paradigm
- Explain the three pillars of sustainability
- Identify trade-offs in traditional economic development
- Describe the importance of the seventeen Sustainable Development Goals from the UN

Introduction

Of all 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, humans, with our roughly 200,000-year history, barely merit attention. 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 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 on the wide diversity of other species that also depend on them (Unit 5.2 and Unit 5.3).

In the past, evolution has resulted in new lifeforms at a faster rate than the extinction of other species, resulting in strong biological diversity (Unit 2 and Unit 3.4). 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 background extinction rate, on par with other mass extinction events of the past. Human beings, just one species among millions, are crowding out most species. Evidence of human interference with the natural world is visible in every ecosystem from the presence of pollutants in the stratosphere to the artificially changed courses of the majority of river systems on the planet. All organisms impact their environment to a degree but the rate, scale, and nature of human-induced global change — particularly in the post-industrial period — is unprecedented in the history of life on Earth.

Review of Human-Induced Global Change

1. Mechanization of both industry and agriculture in the last three hundred years has resulted in vastly improved productivity, which led to an explosion in the amount and types of goods and services. Scientific advances and technological innovations, powered by ever-increasing inputs of fossil fuels and their by-products, have revolutionized every industry and created many new ones. The development of resource-intensive consumer cultures and disposable-centric lifestyles has generated waste at an unprecedented scale. Humans are now responsible for moving more matter across the planet than all natural occurrences (earthquakes, storms, etc.) put together.
2. While the rate of human population growth has been plateauing, the human population is still increasing: every year humans add nearly 100 million people to the planet. The environmental impact varies significantly between countries (and within them). However, the exponential growth of humans, coupled with the ideas in the first point, bring the issue of distribution to prominence. Global inequalities in resource consumption and purchasing power mark the clearest dividing line between the rich and the poor. Present patterns of production and consumption are unsustainable for a global population projected to reach 11

billion by the year 2050. If ecological crises and rising social conflict are to be countered, present rates of over-consumption by a rich minority, and under-consumption by a large majority, need to be brought into balance.

3. It is not only the rate and the scale of change but the nature of that change that is unprecedented. Humans have introduced chemicals and materials into the environment that do not occur naturally OR do not occur in the ratios in which we have introduced them. Persistent 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 currently beyond calculation. Chlorofluorocarbons (CFCs) and polychlorinated biphenyls (PCBs) are two examples of the approximately 100,000 human-derived chemicals currently in global circulation (between 500 and 1,000 new chemicals are being added to this list annually). Most of these chemicals have not been tested for their toxicity on humans and/or natural systems, 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.

Video



In this 5.5-minute Ted-Ed, discover how human impacts have become so pervasive, profound, and permanent that some geologists believe we merit our own epoch.

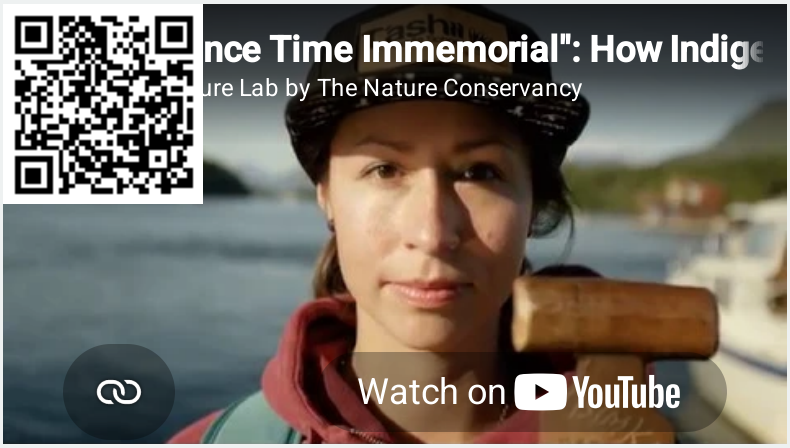
Question after watching: Explain how, to some degree, humans have created a homogenous world.

Sustainability as a Concept

Our Common Future (1987), also known as the Brundtland Report, by the UN's World Commission on Environment and Development, is widely credited with having popularized the concept of **sustainability.** Sustainability is derived from two Latin words: *sus* which means up, and *tenere* which means to hold. Thus, sustainability is about maintaining human existence by meeting the needs of the present without compromising the ability of future generations to meet their 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 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 further to the oral histories of indigenous cultures. 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 a few years, the thought that other human cultures have based their decision-making systems on time scales of many decades seems wise.

Video



This 7-minute video profiles how Indigenous Peoples are reviving traditional stewardship in the temperate rainforests of Clayoquot Sound, BC.

Question after watching: How do the Guardian programs help to maintain the health of the ecosystems and humans in the region?

It is not uncommon to think of sustainability as being a recent interpretation of environmental policy, one that was given credence by the Brundtland Report. However, sustainability did not suddenly come into being at a single moment in time. Most environmental historians who have studied policy have discerned at least three distinct periods of the modern era during which new concepts and ideas, scientific understandings, technological advances, political institutions, and laws and regulations came or were brought into being in order to understand and manage human impacts on the environment.

History of Environmental Movements

1. **The conservation movement:** This 19th-century movement's main objective was the conservation of land and resources and it grew out of opposite philosophies. On one side, those like Gifford Pinchot (first head of the USA's National Forest Service) were very pragmatic about their desire for conservation. For example, conservationists observed that policies for harvesting some resources (like lumber) were not sustainable, so they began sustainability research and new policies so the resources would not run out in the foreseeable future. On the other side were people like John Muir and Theodore Roosevelt that saw land/habitats/wildlife as intrinsic entities, meaning that they had value in their own right, separate from economic value.
2. **Environmental scientists became alarmed by the extent and degree of damage that was being documented:** The publication of *Silent Spring* in 1962 by Rachel Carson (1907-1964), about the impact of the widespread and indiscriminate use of pesticides, was a watershed moment, bringing environmental concerns to the forefront of policy discussions. Carson collected evidence on the effects of pesticides, particularly dichlorodiphenyltrichloroethane (DDT), heptachlor, and dieldrin, on humans, mammals, and birds, and the systemic disruption they caused to ecosystems. *Silent Spring* is credited with bringing about a ban on the use of DDT in many countries. It also set in motion a chain of events that would ultimately result in the transformation of environmental public policy from one based on the problems and attitudes based in 19th-century conservation, to one based on the management of risks from chemical toxins.
3. **The rise of environmental risk management as a basis for policy:** The beginnings of environmental risk management can be traced to the spread of disease, a particularly troublesome problem as the country continued to urbanize in the latter decades of the 19th-century and beginning of the 20th.
4. **The integration of social and economic factors into the sustainability paradigm:** Eventually, humanity realized that in order to solve environmental issues, human social and economic factors had to be accounted for. This is what defines the sustainability paradigm: environmental, social, and economic disciplines. Only superficial solutions can be applied if we only take a one-minded approach.

Video



This 4-minute video explores how, through a change in perspective, we can re-design the way our economy works: designing products that can be 'made to be made again' and powering the system with renewable energy. Question after watching: This process is known as a 'circular economy'. Why do you think it is named this?

Indigenous Connections: UNDRIP

"The High Commissioner for Human Rights welcomed the adoption of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) by the General Assembly on 13 September 2007, as a triumph for justice and human dignity following more than two decades of negotiations between governments and Indigenous peoples' representatives.

It was adopted with 144 votes in favour, 11 abstentions, and four States against (Australia, Canada, New Zealand and the United States of America). Since then, a number of States have changed their position, including the four which voted against but have now endorsed the Declaration.

The Declaration is the most comprehensive instrument detailing the rights of indigenous peoples in international law and policy, containing minimum standards for the recognition, protection and promotion of these rights. It establishes a universal framework of minimum standards for the survival, dignity, wellbeing and rights of the world's Indigenous peoples.

The Declaration addresses both individual and collective rights; cultural rights and identity; rights to education, health, employment, language, and others. It outlaws discrimination against indigenous peoples and promotes their full and effective participation in all matters that concern them. It also ensures their right to remain distinct and to pursue their own priorities in economic, social and cultural development. The Declaration explicitly encourages harmonious and cooperative relations between States and Indigenous peoples." (UN, 2022)

Included in the Declaration are Articles expressing the rights of Indigenous Peoples to practice sustainability as they see fit:

- Article 25:
  - Indigenous peoples have the right to maintain and strengthen their distinctive spiritual relationship with their traditionally owned or otherwise occupied and used lands, territories, waters and coastal seas and other resources and to uphold their responsibilities to future generations in this regard.
- Article 29:
  - Indigenous peoples have the right to the conservation and protection of the environment and the productive capacity of their lands or territories and resources. States shall establish and implement assistance programmes for Indigenous peoples for such conservation and protection, without discrimination.
  - States shall take effective measures to ensure that no storage or disposal of hazardous materials shall take place in the lands or territories of Indigenous peoples without their free, prior and informed consent.

- States shall also take effective measures to ensure, as needed, that programmes for monitoring, maintaining and restoring the health of Indigenous peoples, as developed and implemented by the peoples affected by such materials, are duly implemented.

- Article 31:
  - Indigenous peoples have the right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures, including human and genetic resources, seeds, medicines, knowledge of the properties of fauna and flora, oral traditions, literatures, designs, sports and traditional games and visual and performing arts. They also have the right to maintain, control, protect and develop their intellectual property over such cultural heritage, traditional knowledge, and traditional cultural expressions.
  - In conjunction with Indigenous peoples, States shall take effective measures to recognize and protect the exercise of these rights.
- Article 32:
  - Indigenous peoples have the right to determine and develop priorities and strategies for the development or use of their lands or territories and other resources.
  - States shall consult and cooperate in good faith with the Indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources.
  - States shall provide effective mechanisms for just and fair redress for any such activities, and appropriate measures shall be taken to mitigate adverse environmental, economic, social, cultural or spiritual impact.

Find the full Declaration here: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N06/512/07/PDF/N0651207.pdf?OpenElement

United Nations. 2022. United Nations Declaration on the Rights of Indigenous Peoples. New York, NY. Available from: https://www.ohchr.org/en/publication...genous-peoples

The Three Pillars of Sustainability

As mentioned above, there are three pillars, or dimensions, that sustainability seeks to integrate: economic, environmental, and social (including sociopolitical).

- *Economic interests* define the framework for making decisions, the flow of money, and the facilitation of commerce, including the knowledge, skills, competencies, and other attributes embodied in individuals that are relevant to economic activity.
- *Environmental aspects* recognize the diversity and interdependence within living systems, the goods and services produced by the world's ecosystems, and the impacts of anthropogenic wastes.
- *Social/Socio-political dimension* refers to interactions between institutions/firms and people, functions expressive of human values, aspirations, well-being, ethical issues, and decision-making that depends upon collective action.

The intersection of social and economic elements can form the basis of social "equitability". In the sense of enlightened management, "viability" is formed through consideration of economic and environmental interests. Between environment and social elements lies "bearability", the recognition that the functioning of societies is dependent on environmental resources and services. At the intersection of all three of these lies sustainability (Figure 5.4.1.1).

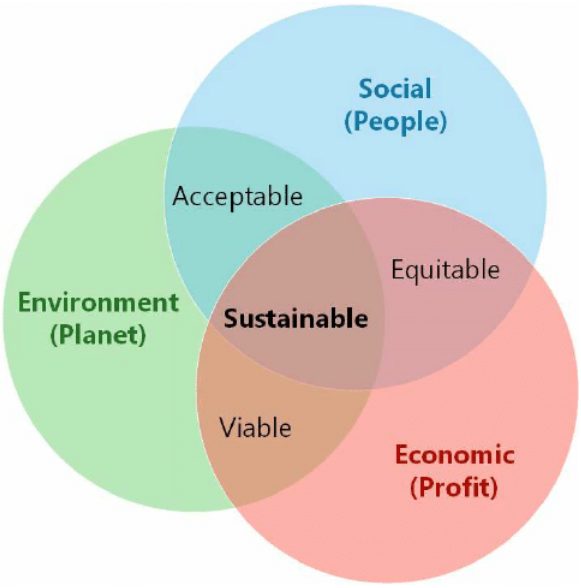


Figure 5.4.1.1: Venn diagram of defining the components of sustainability. Based on “sustainable development” from Wikimedia.org CC-BY.Adapted from United Nations (1987), International Union for Conservation of Nature (IUCN) (2005), Makkar (2013), and Makkar and Ankers (2014).

Trade-Offs

The three main elements of the sustainability Venn diagram above are thought of as equally important. However, tradeoffs occur depending on the local/global objective. For example, it may be deemed necessary to degrade a particular ecosystem in order to facilitate the economy, food production, or housing. In reality, the extent to which tradeoffs can be made before irreversible damage results is not always known. This has led to the notion of '**strong sustainability**', where tradeoffs among natural, human, and social capital are not allowed or are very restricted, and '**weak sustainability**', where tradeoffs are unrestricted or have few limits. Whether or not one follows the strong or weak form of sustainability, it is important to understand that while economic and social systems are human creations, the environment is not. Rather, a functioning environment underpins both society and the economy.

Sustainable development is the progress made toward an economic system that is ultimately based on the wise use of renewable resources. Therefore, a sustainable economy would not deplete its capital of natural resources, and so would not compromise the availability of those necessities for use by future generations of humans. Ecologically-focused sustainable development would allow humans to thrive, but without causing unacceptable damage to other species or natural ecosystems.

By the criteria above, developed economies (such as that of Canada, the United States, countries of Western Europe, Japan, and Australia) are currently unsustainable. There are two major reasons for this conclusion:

1. The continued push of politicians, economists, and other managers of national and international economies for rapid economic growth (both to keep up with an expanding population and to increase the standard of living).
2. The likelihood that the present size of advanced economies is already too large to be sustained for long.

The rationale for these two statements is briefly explained in the following paragraphs.

Economic growth is achieved by pushing both non-renewable and potentially renewable resources through an economy, thereby making the economy larger. Rapid economic growth can be achieved only as long as resources continue to be readily available. However, most non-renewable and potentially renewable resources are rapidly being depleted. Moreover, many scientists and environmentalists believe that the present sizes of advanced economies (such as that of Canada) are already too large to be sustained.

It is common for politicians, corporations, and resource managers to assert that they support sustainability efforts. However, most of them are confusing genuine sustainable development, as it was defined earlier, with “sustainable economic growth.” On a resource-constrained Earth, unlimited economic growth can never be sustained over the long term. Ecologists and environmental economists believe that further growth is undesirable. It is better to limit the economies to a level that can be supported by Earth’s biosphere and resources over the longer term. Fundamental considerations in a sustainable human economy are:

- the number of people that must be supported
- the total intensity of their resource use
- the equitability of standards of living among the world's peoples
- and the environmental damage that is caused

In part, the resolution of resource dilemmas will require a more equitable sharing of wealth among people living in poorer and richer countries. This would moderate the importance of poverty as a key factor in causing environmental degradation.

United Nations' 17 Sustainable Development Goals

A Brief History of the SDGs

"The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests."

- In January 2015, the General Assembly began the negotiation process, culminating in the subsequent adoption of the 2030 Agenda for Sustainable Development, with 17 SDGs at its core, at the UN Sustainable Development Summit in September 2015.
- 2015 was a landmark year for multilateralism and international policy shaping, with the adoption of several major agreements:
  - Sendai Framework for Disaster Risk Reduction (March 2015)
  - Addis Ababa Action Agenda on Financing for Development (July 2015)
  - Transforming our world: the 2030 Agenda for Sustainable Development with its 17 SDGs was adopted at the UN Sustainable Development Summit in New York in September 2015.
  - Paris Agreement on Climate Change (December 2015)
- Now, the annual High-level Political Forum on Sustainable Development serves as the central UN platform for the follow-up and review of the SDGs.

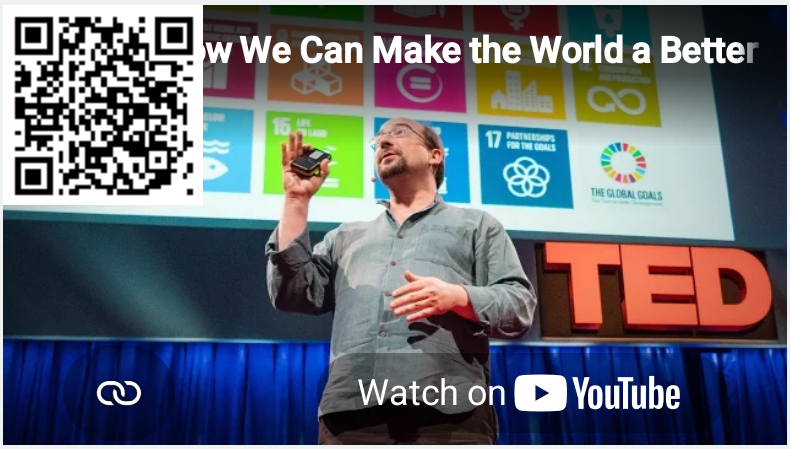
Today, the Division for Sustainable Development Goals (DSDG) in the United Nations Department of Economic and Social Affairs (UNDESA) provides substantive support and capacity-building for the SDGs and their related thematic issues, including water, energy, climate, oceans, urbanization, transport, science and technology, the Global Sustainable Development Report (GSDR), partnerships and Small Island Developing States. DSDG plays a key role in the evaluation of UN systemwide implementation of the 2030 Agenda and on advocacy and outreach activities relating to the SDGs. In order to make the 2030 Agenda a reality, broad ownership of the SDGs must translate into a strong commitment by all stakeholders to implement the global goals. DSDG aims to help facilitate this engagement." (UN, 2022)

Reference: United Nations, 2022. "The 17 Goals: History". New York, New York. Available From: https://sdgs.un.org/goals#history



This 3.5-minute video profiles the seventeen goals that 193 United Nations member states unanimously adopted to achieve by 2030. These are known as the Sustainable Development Goals (SDGs).
Question after watching: Describe ways in which these goals overlap and tie into one another.

Video



In this first 14-minute video from social progress expert Michael Green in 2015, Green invites us to imagine how the UN's Sustainable Development Goals (SDGs) and their vision for a better world can be achieved.
Question after watching: What are some of the trade-offs from progression towards the goals? What were some of the positive signs?

Video



A simple 3.5-minute introduction to sustainable development and the Sustainable Development Goals (SDGs).
Question after watching: Which concepts in this video are review from the textbook? Which are new?

Video



Discover what a sustainable, universally beneficial economy might look like in this 15-minute video.
Question after watching: What ecological limits are taken into account in this model?

Sustainability in Practice

Cities in the 21st century now hold most of the world's population. Sustainable cities are key to balancing a sustainable society, economy, and environment. According to a 2017 report that rated sustainability across 32 indicators, Zurich, Switzerland, was ranked number one. Zurich invests in renewable energies, sustainable public transport, public green space, and public education. One of the most notable ways Zurich is leading global sustainability efforts is its dedication to keeping its carbon dioxide emissions low. Figure 5.4.1.2 below shows the difference in emissions for Canada and Switzerland.

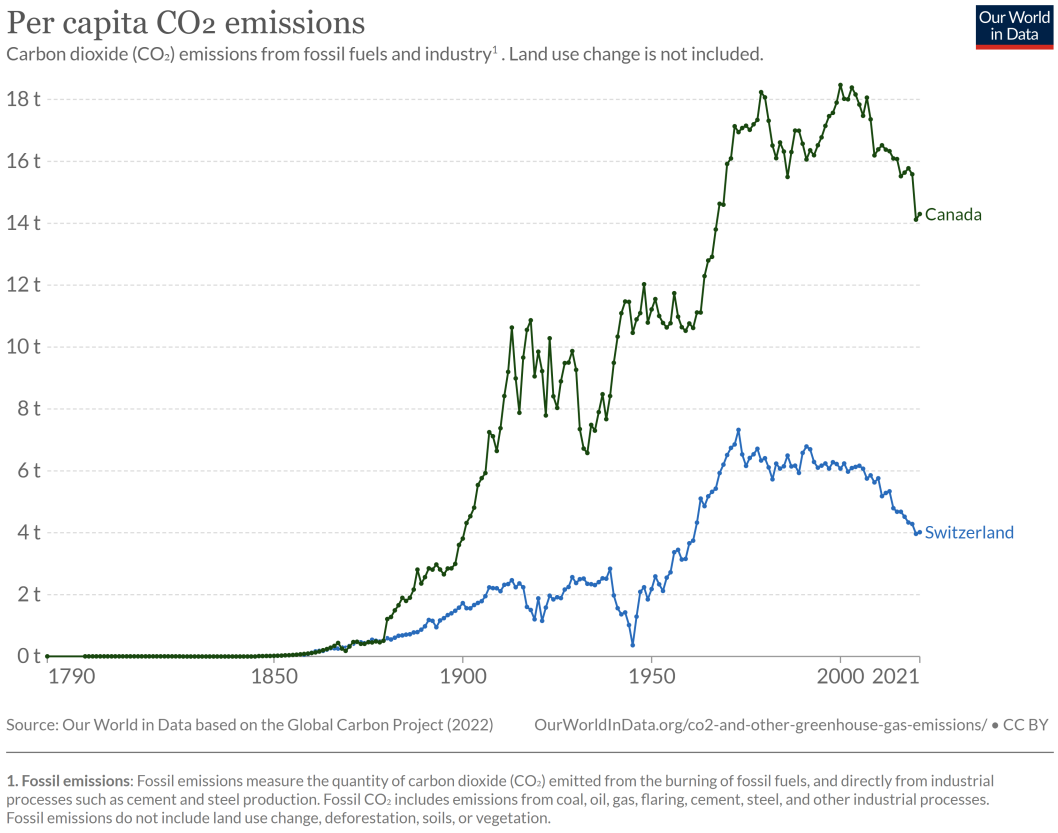


Figure 5.4.1.2: Per capita emissions of carbon dioxide between Canada and Switzerland. Graph by Our World in Data (CC-BY4.0)

Video



More than half of the world's population already lives in cities, and another 2.5 billion people are projected to move to urban areas by 2050. In this 14-minute video, learn how the way we build new cities will be at the heart of so much that matters, from climate change to economic vitality to our very well-being and sense of connectedness. Question after watching: What are the seven universal principles for sustainable cities?

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Unit 5.4.2 - Sustainability Ethics and Environmental Justice

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- Bolded terms are located at the end of the unit in the Glossary. There is also a Unit Summary at the end of the Unit.
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  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Describe how ethics and moral extensionism connect to sustainability
- Explain how true sustainability promotes environmental equity and justice
- Describe the development of the modern environmental ethic
- Identify some of the historical and current perspectives of Indigenous peoples and sustainability

Introduction

Sustainability can be a difficult concept when applied. It dictates that we are constrained by Earth's resources as to the society and lifestyle we can have. On the other hand, sustainability is also a wonderful, inspiring concept and a quintessentially human idea. The experience of our own limits need not be negative. In fact, sustainability is driven by an ethics of the future. To be sustainable is, by definition, to be attentive to what is to come and so it requires imagination. Sustainability teaches that the environment is not a sideshow or a scenic backdrop to our lives. Our relation to our natural resources is the key to our survival. It is the grounds of possibility for everything else. Unsustainability, conversely, means human possibilities and quality of life are increasingly taken away from us and the generations to come.

Precautionary Principle, Sustainability, and Ethics

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 potentially 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.

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, and we know even less about combining activities. In general, however, though we might not have known where the breakdown in a given natural system may lie, the vulnerability of ecosystems to human resource extraction is a constant lesson of environmental history (Unit 5.2). 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 economic growth or individual interests.

Environmental Ethics

The concept of **ethics** involves standards of conduct. These standards help to distinguish between behavior that is considered by society to be 'right' and that which is considered 'wrong'. It is not always easy to distinguish between right and wrong, as there is no universal human code of ethics. For example, a poor farmer clears an area of rainforest in order to grow crops. Some would not oppose this action, because the act allows the farmer to provide a livelihood for his family. Others would oppose the action, claiming that deforestation will contribute to soil erosion and climate change. Right and wrong are usually determined by an individual's morals, and to change the ethics of an entire society, it is necessary to change the individual ethics of a majority of the people in that society.

Moral extensionism defines how far a person's values extend outside of themselves. There are many variables that can influence where the limit lies for each individual person. For example, religion, culture, education, and personal interests, among others, all impact how an individual makes moral judgments. Moral extensionism can be applied to the environment in action and intent. The ways in which humans interact with the land and its natural resources are determined by ethical attitudes and behaviors. The following are major ethical perspectives regarding the natural world.

Frontier Ethic

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 utilitarian and anthropocentric as only the needs of humans are considered.

Most industrialized societies view population and economic growth through this frontier ethic lens, assuming that infinite resources exist to support continued growth indefinitely. In fact, economic growth is usually considered a measure of how well a society is doing. Now that the human population has passed eight 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 world.

Some still subscribing to the frontier ethic suggest that outer space may be the new frontier: we can simply populate other planets if Earth's resources run out. 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 and 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. This 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. He believed that mistreatment of land makes little economic or moral sense. 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)

Environmental Equity

Environmental equity describes a society and culture in which no single group or community faces disadvantages in dealing with environmental hazards, disasters, or pollution. While much progress is being made to improve resource efficiency, far less progress has been made to improve resource distribution. Currently, 20% of the global population is consuming 80% of the Earth's resources.

If the poorest 80% of the world's population were to exercise their right to the same standard of living as the richest 20%, it would result in ecological devastation. To date, global income inequalities and lack of purchasing power have prevented developing countries from reaching the standard of living (and also resource consumption/waste emission) of developed countries. However, countries such as China, Brazil, India, Indonesia, and Malaysia are catching up fast.

In such a situation, global consumption of resources and energy needs to be drastically reduced in developed countries to a point where future generations can have access to those same resources. But who is willing to make those changes? The economies of developed countries demand ever-greater consumption-based expansion. Such stalemates have prevented any meaningful progress toward equitable and sustainable resource distribution at the international level. These issues of fairness and distributional justice remain unresolved.

Video

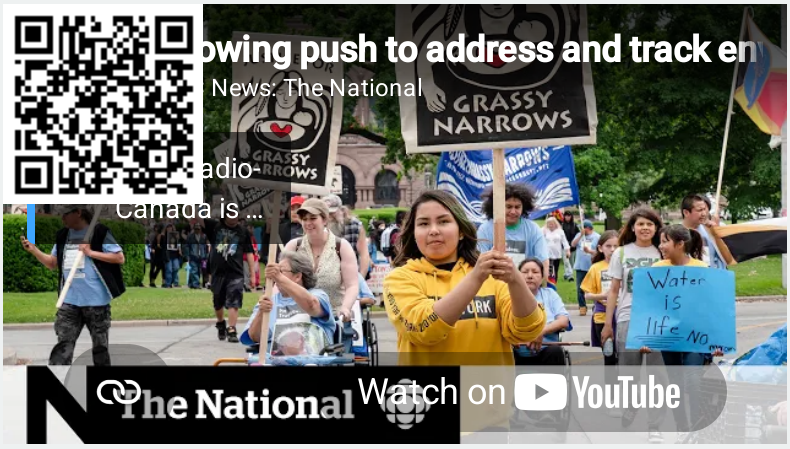


This 2.5-minute video describes SDG 10, which aims to reduce inequality within and among countries by 2030. Question after watching: While each SDG targets specific issues, many of the goals are intertwined. In what ways can achieving other SDGs reduce inequalities?

Environmental Justice

Environmental Justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, ability, 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.

Video



The disproportionate exposure to environmental hazards has long had a larger impact on Indigenous, Black, and other marginalized communities in Canada, as indicated in this 2.5-minute video. A 2021 private members bill is calling for a national strategy to address and track instances of environmental racism.

Question after watching: What would this bill do to help those currently impacted by environmental racism?

In one of the most flagrant cases of environmental injustice in the last decade in a developed country, the city of Flint, Michigan in the United States decided to save money by drawing water for residents from the Flint River in 2014. Soon after, residents complained about the taste, smell, and color of the water. Scientific studies determined that there was a failure to apply corrosion inhibitors to the water, resulting in lead from aging pipes leaching into the water supply, exposing around 100,000 mostly poor residents of color to elevated lead levels. Although the city switched back to its original water source, the damage was already done. Not only did this crisis expose so many to lead, especially concerning for children, but most pipes also needed to be replaced as they were no longer safe to use (Figure 5.4.2.1). In 2017, a settlement was reached to replace all the pipes totaling $87 million USD. However, in 2021 the project had still not been completed. Citywide lead levels have tested within the safe range for consumption, though many houses considered high risk do continue to show elevated levels.



Figure 5.4.2.1: Flint residents trying to bring awareness of Flint Water Crisis through peaceful demonstration. Image by Shannon Nobles, Wikimedia Commons (CC-BY-SA-4.0).

Environmental Racism

Environmental racism was coined in the 1980s to describe the practice of siting hazardous waste sites in minority neighborhoods. In recent decades it has come to describe more fully the institutional racism that exists for marginalized communities in many developed countries regarding landfills, incinerators, waste sites, and industry in neighborhoods. It also describes the long-standing impacts on Indigenous communities and, on an international level, the extractive nature of relationships of developed countries in developing countries.

In an ideal world, there would be no hazardous waste to plague this planet. Unfortunately, we live in a world with rampant pollution, dumping of hazardous wastes, and people with "living for the now" attitudes. Our industrialized society has necessarily produced waste 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 keep the health and wellness of all of their community 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 historically marginalized.

Indigenous People

Since the end of the 15th century, most of the world's frontiers have been claimed and colonized by nation-states. Invariably, these conquered frontiers were already home to Indigenous peoples. 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 a 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."

Many global 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, was "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 was 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. 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. While Indigenous peoples are not a monolith, sustainable development requires the maintenance and continuity of life, from generation to generation. Humans are not isolated entities but are part of larger communities, which include the seas, rivers, mountains, trees, fish, animals, and ancestral spirits, constituting a whole (Figure 5.4.2.2). 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.



Figure 5.4.2.2: Bernadette Demietieff speaking in support of protect the Arctic to protect Gwich'in land from oil drilling, Alaska, c. 2019. Deb Haaland CC-BY-SA-4.0.

Video



In this 3-minute video, Indigenous leaders and other participants at the IUCN World Conservation Congress 2016 discuss the value of Indigenous rights, knowledge, and leadership in creating more sustainable ways of life on Earth.

Question after watching: What commonalities do you hear in the message from all of the diverse Indigenous peoples?

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Unit 5.4.3 - Environmental Policy, Monitoring, and Impact Assessments

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 2 hours.
- Optional Activities are embedded.
- Bolded terms are located at the end of the unit in the Glossary. There is also a Unit Summary at the end of the Unit.
- To navigate to Unit 5.4.4, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Explain how environmental policy has changed based on movements and needs in Canada
- Identify how environmental monitoring and research provide opportunities for planning and mitigation
- Describe the Environmental Impact Assessment process in Canada and give examples

Introduction

Environmental policies are typically driven by problems of the day, real and perceived, that require systemic solutions. For example:

- Early conservationists were alarmed at the inefficiencies of resource management by humans and the encroachment of humans on unspoiled lands, leading to conservation legislation.
- During the 20th century, many groups (scientists, economists, politicians, and ordinary citizens) became alarmed and fearful of the consequences of toxic pollutant loads to the environment that included localized effects on human health and well-being, leading to clean air and water legislation.
- As society proceeds into the 21st century, an array of complex problems that have the potential to alter substantially the structure and well-being of large segments of humanity, founding calls for renewal and reassessment of our approach to environmental policy.

This has, thus far, proven to be a difficult transition. Many of these complex problems have multiple causes and impacts, affect some groups of people more than others, are economically demanding, and are often not as visibly apparent to casual observers as previous impacts, nor are the benefits perceived to be commensurate with costs. Devising a regulatory strategy for such problems requires an adaptive and flexible approach that current laws do not foster.

Table 5.4.3.1: Table illustrating historical development of environmental policy.

	1850-1920	1960-1990	1990-Present
Focus	Conservation/sanitation	Media/site/problem specific	Complex regional/ global problems
Outcome	Land preservation/efficiency/control of disease	Manage anthropocentric and ecological risk	Global sustainable development
Principal Activity	Resource management reform/simple contaminant controls	Compliance/remediation/technological emphasis on problem solving	Integration of social, economic, and technological information for holistic problem solving
Economic Focus	Profit maximization/public health	Cost minimization	Strategic investments/long-term societal well-being
Regulatory Activity	Low	Heavy	Adaptive and flexible
Conceptual Model	Expansion vs preservation	Command and control	Systems/life cycle approach
Disciplinary Approach	Disciplinary and insular	Multidisciplinary	Interdisciplinary/integrative

Many activities that could potentially degrade environmental quality are regulated by legislation passed by various levels of government. In addition, Canada has signed a number of international treaties and protocols that deal with important environmental issues.

Canadian Environmental Law

Environmental law in Canada is made extremely complex by jurisdictional overlaps and other factors. One problem is that of harmonization of related pieces of legislation among the provinces/territories and the federal government. In 1998, these governments adopted the Canada-Wide Accord on Environmental Harmonization, which was intended to achieve progress in this direction. However, that action was resisted by certain interest groups, including the Canadian Environmental Law Association (CELA). CELA views the accord as a mechanism for devolving federal environmental roles and responsibilities to the provinces and territories. Canadian environmental law is changing rapidly as new legislation is passed and older laws are modified or more specifically interpreted by the courts.

Indigenous Connections: Environmental Law

In 1999, the Supreme Court's Marshall decision involved a case in which an Indigenous person had been convicted of catching fish out of season, without a license, and for commercial sale. This conviction was overturned on the basis of treaty rights, negotiated in 1760-1761, that guaranteed Mi'kmac and Maliseet Indians the right to commercially harvest natural resources at any time of year within an extensive treaty area in the Maritime Provinces. The Supreme Court interpreted the modern resource-harvesting rights of those Indigenous nations as being sufficient for individuals to earn a "moderate living." The Marshall decision restored to Indigenous peoples a legal right to engage in fish and timber harvests that are not subject to the same seasonal and geographical restrictions as for non-Indigenous people. The Marshall decision resulted in controversy and conflict with government agencies and non-Indigenous fishers.

In 2003, the Supreme Court extended aspects of the Indigenous resource-access rights to Métis in Canada, ruling that those persons could also freely hunt and fish for subsistence purposes. Some key issues were left unresolved, such as the definition of a Métis person as well as restrictions that might be imposed for the purposes of safety and resource conservation. These aspects are being resolved through ongoing negotiations of interest groups with federal, provincial, and territorial governments. The social and economic repercussions of these decisions by the Supreme Court of Canada will take years to work out.

Subsequent decisions of the Supreme Court in 2013 and 2014 have clarified Indigenous rights to land tenure and resource rights in British Columbia. These cases involved proposals to build mines and oil pipelines in areas where First Nations has not signed land-claim agreements with the provincial government and as such had never ceded their rights to property in areas

where large industrial developments were being proposed. In essence, the Supreme Court affirmed those Indigenous rights. Although the implications of that decision are not yet fully appreciated (it is likely that additional legal actions will be needed to accomplish this), it appears that substantial negotiations will be needed to gain Indigenous approval for industrial projects being proposed within their domain.

The settlement of comprehensive land claims with Indigenous nations in Canada (in effect, the modern equivalent of "treaties") includes the formulation of suites of environmental laws. For example, such settlements include provisions that govern many aspects of resource harvesting and management, waste management, and protected areas within the settlement regions.

An important example of the need for effective legislation concerns the protection of species at risk and their habitat. That sort of legislation has existed in the United States since 1973 as the Endangered Species Act (ESA) administered by the Fish and Wildlife Service (2015). As of 2014, 1,330 species of animals and 889 species of plants were listed as endangered or threatened under the ESA (685 of the listed animals occur in the United States and 645 in other countries, while 886 of the plants grow in the United States and three elsewhere). In addition, approved recovery plans were in place for 479 of the listed U.S. animals and 676 of the plants.

In Canada, the conservation status of species is designated by a group of experts from the government, conservation organizations, and academia known as COSEWIC (the Committee on the Status of Endangered Wildlife in Canada). As of 2014, COSEWIC had assigned at-risk status to 721 indigenous species and other taxa (such as subspecies; only native taxa are designated). Moreover, in 2002, a federal **Species at Risk Act (SARA)** became law. SARA has toughened the legal provisions in support of the protection of species listed by COSEWIC. Its provisions are particularly strong with respect to at-risk species and their habitat occurring on lands owned by the federal government or otherwise falling within its jurisdiction.

However, the SARA legislation is much weaker with respect to species and critical habitat on lands beyond direct federal jurisdiction, such as areas owned by provincial, territorial, municipal, Indigenous, or private interests. Although there are provisions in SARA for the federal government to intervene in such cases, and to provide compensation to affected landowners, it is not bound to do so. Many such interventions would inevitably be expensive and controversial, and so far this mechanism has not been used much to protect at-risk species in Canada. Most of the provinces and territories have also passed laws related to the protection of species at risk within their own jurisdictions, or they are preparing such legislation.

Of course, it is not sufficient to simply pass good laws that are intended to regulate actions that might degrade the quality of the environment – it is also necessary to enforce them. Between 2011 and 2015, there were 95 successful prosecutions (that is, with a conviction) under the Canadian Environmental Protection Act (CEPA) or the Fisheries Act. There are, however, a much larger number of cases that can be resolved with softer regulatory actions, such as writing a warning letter to a non-compliant party.

Several non-governmental organizations have taken on the mandate of advocating improvements to environmental law and policy in Canada, while ensuring that the existing laws are rigorously applied. The most prominent of these are the Canadian Environmental Law Association and Ecojustice. These organizations lobby politicians and suggest specific changes to existing or proposed legislation. In some cases, they also take government agencies to court in order to force them to enforce the existing laws or to seek interpretation from a higher court such as the Supreme Court of Canada.

Environmental Monitoring and Research

There are widespread and well-founded concerns about severe damage being caused to the quality of the environment. In response, many nations are implementing programs to monitor changes in environmental quality over time. Most of these programs are intended to document changes that are occurring over large regions or entire countries and to help predict future variations. These efforts are much larger in scale and scope than programs that monitor whether a particular industrial facility is complying with regulations and guidelines. Most large-scale monitoring is conducted by governmental agencies, or in some cases, by non-governmental organizations. The resulting data and knowledge are used to guide decision-making in government, enhance the work of NGOs, and provide material for environmental research and education.

In the sense meant here, environmental monitoring involves repeated measurements of factors that are related to either the inorganic environment, the structure and functioning of ecosystems, and any intersections with human welfare. Because not everything can be monitored, successful monitoring programs depend on the careful choice of a limited number of representative

indicators and on the collection of reliable data. If a monitoring program detects important changes, the possible causes and consequences of those changes are usually researched.

Video



This 2.5-minute video gives a brief explanation of what environmental indicators are, and their role in allowing us to measure the condition of environmental assets (e.g. soils, vegetation, fauna).
Question after watching: What environmental indicators do you think are used in the ecosystems around you?

Suppose that environmental monitoring has detected that precipitation has become acidified in a large region. The cause(s) of the acidification might be understood by determining the concentrations of chemicals in the precipitation and by investigating local emissions of gases and particulates to the atmosphere. Researchers must also understand the consequences of increased deposition of acidifying substances to freshwater and terrestrial ecosystems, as well as the implications for buildings and other urban features. At first, the research would examine the existing knowledge of the causes and ecological effects of acidification in various kinds of habitats. However, that knowledge is always incomplete and, therefore, it must be augmented with new research examining the risks of acidification that are not yet understood. The accumulated information helps society to understand whether the causes of acidification can be controlled and, if so, to assess the potential environmental and economic benefits.

In another example, monitoring might indicate that the ecological character of a region is changing because the natural forest is being extensively converted into plantations through industrial forestry. The ecological consequences would initially be interpreted in the light of existing knowledge of the effects of forestry, supplemented by additional research that investigates poorly understood issues. Specific research questions might address the effects of ecological conversions on biodiversity, forest productivity, watershed hydrology and chemistry, and global environmental change through effects on carbon storage. This information is needed to help decision-makers evaluate whether they should permit further conversions of natural forests into plantations.

Video



Environmental monitoring provides a health assessment of environmental assets such as agricultural soils, rivers, native vegetation, and wildlife, as profiled in this 2.5-minute video.
Question after watching: How do you think the assets are selected?

Environmental Monitoring and Research in Canada

Environmental monitoring and research in Canada are carried out by various agencies. Environment Canada is the most active agency at the federal level. In addition, the Department of Fisheries and Oceans deals with fisheries and oceanic environments, Natural Resources Canada provides data about non-renewable and some renewable resources, the Canadian Forest Service provides information relevant to commercial forests, Parks Canada examines changes in national parks, and Health and Welfare Canada deals with influences of environmental quality on human health. Statistics Canada plays a key role in compiling information and making it available to governments, companies, and the public. All of the provincial and territorial governments of Canada also have comparable agencies that deal with environmental issues within their jurisdiction.

A few non-governmental organizations also undertake a considerable amount of environmental monitoring and research. For instance, the World Wildlife Fund-Canada has programs that fund work on endangered species and ecosystems. The Nature Conservancy of Canada is active in work associated with conservation planning and stewardship. Universities also have considerable technical expertise in environmental issues. University personnel are not necessarily involved in long-term monitoring programs, but many professors and graduate students undertake research into the causes and consequences of environmental changes.

Environmental monitoring programs provide society with crucial information and knowledge. Both are necessary for the implementation of effective programs to prevent further degradation of environmental quality and the health of ecosystems and to repair existing damage. These actions are necessary if society is to conduct its economy in a truly sustainable manner.

Video



This is a 6-minute profile of a day-in-the-life of an environmental technician.
Question after watching: What surprised you about the job and what it entailed? Is this a position you might be interested in pursuing?

Notions of Environmental Quality

Environmental quality, ecosystem health, and ecological integrity are important notions that help us understand the importance of changes in environmental conditions. However, like other notions, these ones cannot be precisely defined, although it is possible to develop a general understanding of what they mean.

Because they integrate changes in many components of ecosystems and environments, these concepts involve complex phenomena. **Environmental quality,** for example, is related to the concentrations of potentially toxic chemicals and other stressors in the environment, to the frequency and intensity of disturbances, and to the effects of these on humans, other

species, ecosystems, and economies. Of particular concern are stressors associated with human activities, because these have become so important in the modern world.

Ecosystem health and ecological integrity are similar to each other and, in many respects, to environmental quality. However, these indicators focus on changes that may be occurring in natural populations and ecosystems, rather than on the effects on people and their economy. All of these notions involve many variables that are related to stressors and socio-economic or ecological responses. As a result, they are sometimes measured using composite indicators, which integrate many possible changes that are thought to be important. Composite indicators are not exact measurements of environmental quality, ecosystem health, or ecological integrity, but they do allow society to determine whether conditions are getting worse or better.

These ideas can be explained by using **ecological integrity** as an example. Obviously, most stressors associated with human activities will enhance some species, ecosystems, and ecological processes, while at the same time damaging others. However, ecological theory suggests that systems with higher values for any or all of the following characteristics will have a greater degree of ecological integrity:

- The ecosystem is resilient and resistant to changes in the intensity of environmental stressors
- The system is rich in indigenous biodiversity values
- The ecosystem is complex in its structure and function
- Large species are present
- Top predators are present
- The ecosystem has controlled nutrient cycling, meaning it is not “leaking” its nutrient capital
- The ecosystem has a “natural” character and is self-maintaining, as opposed to being strongly affected by human influences and management

These sorts of criteria for ecological integrity are of particular relevance to managing protected areas. If ecological integrity is being maintained or enhanced, then a protected area is doing its job of maintaining biodiversity and ecological functions.

Successes

As we noted earlier, programs of monitoring and research should be capable of detecting changes in environmental quality, while also helping to predict future effects. Well-designed programs should deal with the most important known stressors or potential threats to the environment. They should measure or predict the effects on people and on sensitive ecosystems and species, particularly those that are economically or ecologically important.

These are the simple requirements of a sensible program for monitoring and investigating environmental problems. Unfortunately, these criteria are not well met by many existing programs, and as a result, some important environmental problems are not yet well understood. Consequently, they are not being addressed effectively, and they could become worse in the future. To deal properly with these and many other important issues, we must improve our understanding through better monitoring and research. We can illustrate the achievable benefits by examining a few “success stories” in which monitoring, research, and effective actions helped to resolve important environmental problems.

- Eutrophication of fresh water was identified as an important environmental problem during the 1960s and early 1970s. Research discovered that phosphate was the primary cause and that the damage could largely be avoided by constructing sewage-treatment facilities and by using low-phosphorus laundry detergent.
- Acidification (acid rain) was recognized during the late 1970s and the 1980s as an extensive phenomenon causing many ecological damages. Research showed that the problem was largely due to the atmospheric deposition of sulphur and nitrogen compounds. This convinced decision makers to require reductions of industrial emissions, and that action led to some improvements.
- Contamination with persistent chlorinated hydrocarbons, such as DDT, dieldrin, and PCBs, was found to be widespread in the 1960s and 1970s. Research showed that some species, such as predatory birds, were being seriously harmed and that there were possible effects on humans. The toxicological evidence convinced decision makers to ban these chemicals in most countries, to the great benefit of the environment.

Video



In this 5.5-minute video, discover the groundbreaking environmental work of Rachel Carson, whose book Silent Spring explores how human actions threaten the balance of nature.
Question after watching: Why were so many people critical of Carson and Silent Spring? How did she challenge the status quo?

Environmental Impact Assessments

One important interpretive decision of the Supreme Court of Canada affecting environmental impact assessments was the Rafferty decision of 1989, which made it clear that an Environmental Impact Assessment was needed for any undertakings involving the federal government. An **environmental impact assessment (EIA)** is a planning process that is used to help prevent environmental problems. Environmental impact assessments do this by identifying and evaluating the potential consequences that a proposed development may have for environmental quality. Because it can consider ecological, physical-chemical, and other environmental effects, as well as socio-economic consequences, an EIA is a highly multidisciplinary and interdisciplinary activity.

An EIA may be conducted to examine various kinds of activities, or planned developments, that could affect environmental quality, such as the following:

1. an individual project, such as a proposal to construct an airport, dam, highway, incinerator, mine, or power plant
2. an integrated scheme, such as a proposal to develop an industrial park, a pulp or lumber mill with its attendant wood supply and forest-management plans, or other complex developments that involve numerous projects
3. a governmental policy that carries a risk of substantially affecting the environment

The scale of an environmental assessment can vary greatly, from the examination of a relatively small proposal to construct a building near a wetland, to a megaproject associated with natural-resource development.

Canadian EIAs

In Canada, environmental impact assessments for proposals that involve federal funding or jurisdiction are regulated under the **Canadian Environmental Assessment Act (CEAA)**, which was enacted in 1992. The Act is a law that requires federal decision-makers, referred to as “responsible authorities,” to consider the predicted environmental effects of a proposed project before it is allowed to go ahead. If significant adverse effects are predicted, the project is not allowed to proceed until the damages have been addressed by a change in design or through some other mitigation.

Figure 5.4.3.1: Impact assessment process overview. Copyright: Government of Canada.

Initially, the CEAA required that EIA studies be done on a wide range of projects involving the jurisdiction of the federal government. However, in 2012 the Act was greatly weakened by requiring that only big projects are considered. Provinces and territories also have legislated requirements for EIA, as do some local levels of government, such as municipalities and First Nations.

EIA is based on the reasonable premise that all proposed projects, programs, and policies carry risks for human welfare and for other species and ecosystems. For example, a proposed project may emit toxic chemicals into the environment. In such a case, it is necessary to determine if the anticipated emissions might exceed the regulated levels. The most stringent standards and guidelines are related to the maximum exposures that humans can tolerate without suffering risks to their health, while criteria to protect other species and ecosystems are less exacting. For example, the guideline for uranium in drinking water is 0.02 mg/L, but that for the protection of aquatic life is 40 mg/L for short-term exposure (<1-4 days) and 5.5 mg/L for long-term exposure.

In addition, a project might cause disturbances to natural habitats during its construction or operation, which could result in ecological damage. These effects should be identified and quantified, and the potential environmental damages evaluated before permission is granted to start the project.

The process of environmental impact assessment is intended to predict these potential damages and to suggest ways of avoiding or mitigating them as much as possible. However, this does not necessarily mean that no damage will be caused by a proposed development. In almost all cases, some damage is inevitable.

Video



Impact assessments help society understand the possible impacts of projects before they start, as detailed in this 2-minute video.

Question after watching: In what ways can individuals or groups give feedback on an EIA in Canada?

Because most developments potentially affect a great variety of species and ecosystems, EIAs are limited to predicting the effects on only a selection of so-called **valued ecosystem components (VECs)**. These components are valued because society perceives them to be important for one or more of the following reasons:

1. They are an economically important resource, such as an agricultural crop, a commercial forest, or a stock of fish, mammals, or birds
2. They are a rare or endangered species or ecological community
3. They are of cultural or aesthetic importance

Cumulative Environmental Effects EIA

The Cumulative Environmental Effects EIA is a planning activity under the Canadian Environmental Assessment Act that includes the need to evaluate cumulative environmental impacts, or those resulting from the effects of a proposed undertaking within some defined area, in addition to those caused by any past, existing, and imminent developments and activities. The concept of cumulative effects recognizes that the environmental effects of separate anthropogenic influences will combine and interact to cause changes that may be different from those occurring separately. Assessment of cumulative impacts requires knowledge of both the likely effects of a proposed development, as well as those of other anthropogenic activities in a study area, plus additional ones that are likely to occur.

There are a number of examples of cumulative environmental effects that are primarily ecological and have occurred in Canada:

- aggregate damage caused to populations of migratory salmon in the Fraser River watershed in British Columbia as a result of commercial fishing in the open Pacific or in the river itself, along with sport and subsistence fishing, plus degradation of freshwater habitat through such influences as the dumping of sewage, agricultural erosion and pesticides, warmer temperatures and woody debris in streams caused by forestry operations, risks of sea-louse infection from aquaculture in coastal waters, and warming oceanic waters caused by climate change
- losses of biodiversity throughout Canada, but particularly in southern regions, caused by deforestation to develop land for urbanized and agricultural uses, fragmentation by roads and transmission corridors, disturbances by forestry and mining, and various kinds of pollution
- ecological damage in a region of boreal forest in northern Alberta in which there are diverse anthropogenic stressors associated with timber harvesting, exploration, and mining for oil and gas, oil-sand extraction and processing, and pipelines and roads to service all of those economic activities
- threats to the ecological integrity of national parks that are associated with the internal development of infrastructure to support tourism, such as campgrounds, interpretation centers, roads and trails, golf courses, and skiing facilities, along with economic activities in the surrounding area such as forestry and agriculture, as well as regional influences such as acid rain and climate change. A requirement that environmental impacts be studied in a cumulative manner acknowledges the complexity of ecosystems and the fact that all aspects of their structure and function are affected by a diverse array of influences.

Much more detail on the full Environmental Impact Assessment process can be found here: https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/impact-assessment-process-overview.html

Planning Options

If, during an EIA, potentially important risks to human welfare or VECs are identified, a number of planning options must be considered. There are three broad choices.

- *Prevent or Avoid*: One option is to avoid the predicted damage by ensuring that there are no significant exposures of people or VECs to damaging stressors related to the project. This can be done by modifying the characteristics of the project, or in cases of severe conflicts with human welfare or ecological values, by choosing to cancel it entirely. Because prevention and avoidance may involve substantial economic costs, this is sometimes considered to be the least desirable option by proponents of development. Politicians and regulators may also dislike this option since it may involve intense controversy. Nevertheless, there is always public and regulatory pressure to take as many precautions as possible before undertaking a proposed development.
- *Mitigation*: Another option is the mitigation of any predicted damages, or to repair or offset them as much as possible. Because any direct damage to people is considered unacceptable (and therefore to be rigorously avoided), mitigation is most relevant to damage inflicted on VECs or to indirect, low-level risks to people. For instance, if the habitat of a valued species is threatened, it may be possible to create or enhance habitat at somewhere else so that the damage is offset. For example, a wetland may be unavoidably destroyed by a proposed development, but the damage may be offset through the creation of a comparable wetland elsewhere (note that this does not help most organisms living in the original wetland). Mitigations are a common way of dealing with potential conflicts between project-related stressors and VECs. However, it is important to understand that mitigations are never complete, often do not address the underlying problem, and there is often residual damage.
- *Accept the Damages*: The third option is for decision-makers to choose to allow a project to cause some or all of the predicted damages to human welfare or VECs. This choice is often considered tolerable by project proponents and by politicians. Their rationale is the perceived socio-economic benefits gained by proceeding with a project are likely to be much greater than the costs of environmental damage. From an environmental perspective, however, this choice might not be viewed as being acceptable, usually because environmental “costs” are grossly undervalued.

Environmental impact assessments generally find that a proposed development carries risks of causing some degree of environmental damage. Usually, the development is allowed to proceed in some form, with the predicted damage being avoided or mitigated to the degree that is considered technologically and economically feasible. As noted previously, however, there are always residual risks that cannot be avoided or mitigated. Any damage that does occur represents some of the environmental costs of development, which are real even if there is financial compensation or other kinds of offsets.

Once a project has begun, compliance monitoring is usually necessary to ensure that regulatory criteria for pollution or health hazards are not being exceeded. It is extremely useful, although not always required, to also monitor the ecological effects of a project. This tests the predictions of the impact assessment and identifies unanticipated effects or "surprises." Ideally, a monitoring program for ecological effects is begun before a project starts, in order to establish the baseline conditions. The monitoring should then continue for some years after the project is completed until it is determined that important damage is not being caused. If unanticipated damage is shown by the monitoring, it may be prevented, avoided by an adaptive change in the project design, mitigated in some way, or accepted as an ecological "cost" of development.

Examples of Environmental Impact Assessments

EIAs have been conducted in all regions of Canada, examining projects that varied widely in both scale and potential effects. Each of these unique cases is instructive, in the sense of illustrating the environmental implications of development projects and the role played by impact assessment. In the following sections, we briefly examine selected elements of some environmental impact assessments in Canada.

Diamond Mines in the Northwest Territories

This proposal involved the development of mines to extract diamonds from five deposits discovered about 300 km northeast of Yellowknife. A variety of potential environmental damages were identified with this project. First, some of the diamond-bearing rock lies beneath lakes that would have to be drained to develop a mine. These aquatic ecosystems would be destroyed.

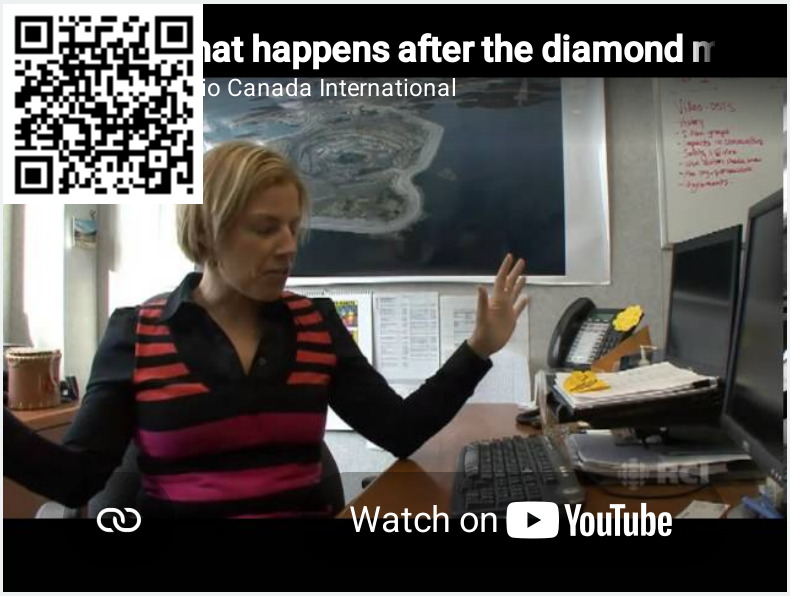
In addition, large amounts of gravel are needed to construct roads and other infrastructure. Much of this material would be obtained from long, sinuous geologic features known as eskers, which are left over from glaciers and provide critical denning habitat for grizzly bear, wolf, and other high-profile species.

Further, large numbers of caribou traverse the region during their seasonal migrations. These are potentially affected by the mine and its network of roads. Substantial damage to the caribou would harm the Aboriginal people in the region, who engage in a subsistence hunt for these animals. Those people might also suffer from interference with their commercial harvest of fur-bearing mammals.

Finally, the proposed mines are located in a region that was a huge, roadless wilderness. Conservationists, led by the World Wildlife Fund, objected to the approval of the mine before a system of protected areas was set up in the region for the preservation of natural ecosystems and native species, including large carnivores such as grizzly bear, wolf, and wolverine.

The diamond-mine proposal passed its environmental impact assessment and was allowed to proceed. It was subject to stringent requirements, however, such as the implementation of acceptable methods of disposal of mining and milling wastes and the protection of water bodies and rivers (other than those that must unavoidably be damaged to develop the mines and dispose of tailings). A ban was imposed on local hunting by project personnel. As well, a monitoring program was to be undertaken to ensure that unanticipated damage is not caused to air or water quality or to wildlife. The mine must also meet socio-economic criteria, including several that deal with employment opportunities and other ways of engaging local people (including Aboriginals) in the development. As a measure outside the scope of the formal impact assessment, the government of the Northwest Territories committed to establishing protected areas in the larger region, although this has not yet been followed through in its entirety.

Video



This 4-minute video is an interview with the Superintendant for Sustainable Development, Communities, and External Relations at Diavik Diamond Mines Inc. by Radio Canada International in 2013 on plans for the eventual closing of the mine.

Question after watching: What environmental, social, and economic considerations are being taken into account during this mine closure plan to make it sustainable?

Destruction of Diseased Bison

Agriculture Canada proposed to slaughter almost all the bison in the southern region of Wood Buffalo National Park and its vicinity. Some of these animals are infected with bovine tuberculosis and brucellosis, and there are concerns over the potential spread of these diseases to herds of cattle to the south and west of the area. The bison targeted for slaughter are hybrids between the indigenous wood bison and plains bison that were introduced to the region during the late 1920s. The proposal did not include the elimination of small populations of genetically "pure" wood bison living farther to the north, and in fact, these were predicted to receive a measure of protection from the potentially harmful effects of interbreeding with hybrid animals.

This proposal was made in support of commercially important livestock interests, but it quickly engendered intense controversy. It was opposed by virtually all conservationists and by local Indigenous people. Although this project successfully passed the impact assessment process, it was later suspended by the federal Minister of the Environment, largely in recognition of the intense opposition from conservation and First Nation interests.



Figure 5.4.3.2: Plains bison (Wilson Hui; CC BY 2.0.)

The Roberts Bank Terminal 2 Project

The Vancouver Fraser Port Authority is proposing a new three-berth marine-container terminal at Roberts Bank in Delta, B.C. The projected cost of the terminal is approximately $3.5B. The Environmental Impact Assessment was conducted by an independent Review Panel. On March 27, 2020, the Review Panel submitted its report containing its conclusions and recommendations.

In August 2020, after considering the Review Panel's report, the Minister determined that additional information is required from the Port Authority to inform the decision on whether the Project is likely to cause significant adverse environmental effects under the *Canadian Environmental Assessment Act, 2012*. This information request pauses the federal timeline for decision-making. Following receipt of this information from the Port Authority, the Government will have approximately three months to make a final decision on the Project. In the interim, IAAC is coordinating post-panel-Report consultations, including coordinating consultations with the Province of B.C. and Indigenous groups. The responses from the Vancouver Fraser Port Authority were subject to an extended public comment period that closed on March 15, 2022. Comments, including those from expert federal departments, were posted publicly and are being reviewed.

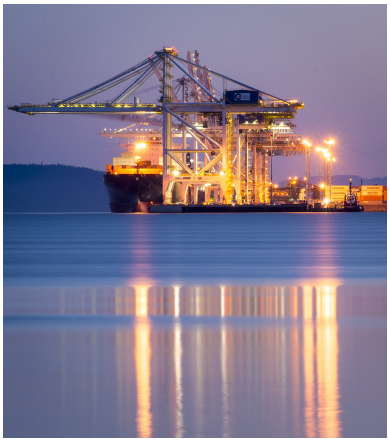


Figure 5.4.3.1: Roberts Bank, 2013 (Gord McKenna; CC BY-NC-ND 2.0)

Nova Scotia Peat Mine

Peat mined from bogs is used as a horticultural material, and it can also be burned as a source of energy. This proposal would have developed a mine on a bog in Nova Scotia to provide peat as an industrial fuel (Figure 5.4.3.2). The EIA focused on the fact that the bog in question provides habitat for several rare species, including a carnivorous plant called the thread-leaved sundew (*Drosera filiformis*). This species is endangered in Canada and also in much of the rest of its range in the eastern United States. Because the bog harbors the largest of only four known populations of the sundew in Canada, the provincial Minister of the Environment did not allow a mine to be developed on that site. This was a controversial decision because it canceled a local development initiative in a region in which the economy is chronically depressed.



Figure 5.4.3.4: The thread-leaved sundew (Drosera filiformis) and its bog habitat. The largest known population of this carnivorous plant in Canada occurs on a site in southwestern Nova Scotia that was proposed for a peat mine. An environmental impact assessment predicted that the mining would obliterate the most important population of this endangered species, and as a consequence, the Government of Nova Scotia did not allow the mine to proceed. Source: Bill Freedman.

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Unit 5.4.4 - Sustainability and the Future

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- Bolded terms are located at the end of the unit in the Glossary. There is also a Unit Summary at the end of the Unit.
- To navigate to the Unit Glossary and Summary, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Describe how lifestyle choices influence sustainability
- Recognize important Canadian governmental bodies and international organizations responsible for sustainability
- Explain the importance of environmental citizenship and literacy
- Describe the multi-faceted approach required for sustainability

Introduction

Sustainable development was previously defined as progress made toward an economic system that is ultimately based on the wise use of renewable resources. A sustainable economy would not deplete its capital of natural resources, and so would not compromise the availability of those necessities for use by future generations of humans. We also noted that ecologically sustainable development would allow human activities to continue, but without causing unacceptable damage to other species or natural ecosystems.

This text does not give a falsely optimistic view of the future: sustainability will be a challenge and will take a lot of hard work. All levels of society have a responsibility to protect the quality of our common environment. These obligations are a central aspect of the social contract by which enlightened communities function.

The role of government is an overarching one because it is empowered to regulate the activities of itself, the private sector, non-governmental organizations, and individuals. Of course, many activities of government and the private sector carry risks of causing environmental damage, and there is always an obligation to avoid or mitigate the damage as much as possible.

The role of **environmental non-governmental organizations (ENGOs)** is to lobby government and industry about issues, to raise public awareness, and increasingly (because of shortages of governmental capability), to raise funds that can be used to prevent and repair environmental damage. Finally, all individual citizens have an obligation to live their lives in an environmentally responsible manner.

International Organizations

The **United Nations Environment Programme (UNEP)** is the principal international organization that deals with environmental matters. UNEP is responsible for coordinating global environmental efforts with other agencies of the United Nations, national governments, and non-governmental organizations. UNEP also coordinates the development of multinational treaties and other agreements and periodically hosts global conferences on environmental themes.

Other agencies of the United Nations also have mandates that involve environmental issues. These include the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Population Fund (UNPF), the World Health Organization (WHO), and the International Labour Organization (ILO).

A wide range of non-governmental environmental organizations are also active on the international stage:

- ENGOs involved in the international conservation of biodiversity include Conservation International, the Cousteau Society, the International Union for Conservation of Nature and Natural Resources, the Nature Conservancy (U.S.), the Smithsonian Institution, and the World Wildlife Fund.
- Those with general mandates concerning resources and other environmental issues include the Earth Island Institute, the Environmental Policy Institute, Resources for the Future, the Sierra Club, the World Resources Institute, and the Worldwatch Institute.

Video



The Convention on Biological Diversity identifies the Nayoga Protocol in this 2-minute video: a call to expand the global biodiversity framework to include the full and effective participation of Indigenous peoples and local communities.

Question after watching: Why is it important to share natural resources equitably? What are some challenges to achieving this goal?

Canadian Organizations

At the federal level, **Environment and Climate Change Canada** plays a central role in preserving and enhancing environmental quality. Its mandate includes the protection of water, air, and soil quality, renewable resources, and biodiversity. Its institutional objective is to foster a national capacity for sustainable development, in cooperation with international, provincial, territorial, municipal, and Indigenous governments, as well as other departments of the federal government, the private sector, and non-governmental organizations. It is also responsible for informing "Canadians about protecting and conserving our natural heritage, and ensuring a clean, safe and sustainable environment for present and future generations."

Other agencies of the federal government also have important environmental mandates:

- Natural Resources Canada deals with mineral and forest resources, including aspects of the environmental impacts of mining, the use of fossil fuels, and forestry
- Health and Welfare Canada deals with environmental issues related to human health and also has primary jurisdiction over pesticide registrations
- Agriculture and Agri-Food Canada deals with issues involving agricultural practices, including sustainability and pesticide-use registrations
- Fisheries and Oceans Canada is mandated to promote understanding, conservation, and beneficial use of aquatic bio-resources.
- The Canadian Coast Guard helps to protect the marine environment by preventing marine pollution
- Parks Canada manages national parks
- Crown-Indigenous Relations and Northern Affairs Canada is responsible for environmental and resource issues in extensive northern regions
- The Canadian Environmental Assessment Agency conducts environmental assessments of projects involving the federal government

- Statistics Canada compiles environment-related data and makes them available to other agencies and the public

All of the provincial and territorial governments have agencies similar to those listed above for dealing with environmental responsibilities under their jurisdiction. Environmental reporting is one process that is used to communicate information about the environment to the public. Such reporting should involve clear and objective presentations of information about changes in environmental quality, and should also offer unbiased interpretations of the causes and consequences of those changes.

Environmental reporting is delivered to the broader public by various federal agencies, including government departments, educational institutions, non-governmental organizations, and the mass media. Most of the provinces have also released periodic state-of-the-environment reports. Various other federal agencies also make available useful information about the environment available to the public, including Statistics Canada.

Canada also has a wealth of non-governmental organizations that deal with environmental issues. National organizations that focus on the conservation of biodiversity include the Canadian Parks and Wilderness Society, the Canadian Wildlife Federation, Nature Canada, the Nature Conservancy of Canada, and the World Wildlife Fund of Canada (Figure 5.4.4.1). Organizations with general mandates concerning resources and other environmental issues include the Canadian Arctic Resources Committee, Canadian Ecology Advocates, Ducks Unlimited Canada, Energy Probe Research Foundation, Pollution Probe, the Royal Society of Canada, the Sierra Club (Canada), the Tree Canada Foundation, and Wildlife Habitat Canada. In addition, all of the provinces and territories have non-governmental organizations that deal with environmental issues on a more regional basis.



Figure 5.4.4.1: The Nature Conservancy of Canada is an ENGO whose activities focus on acquiring land or land-use rights for the protection of natural values. This project involved the purchase of property on an island in Nova Scotia that provides habitat for several rare plants, including the best-known locale in Canada of the eastern mountain avens (Geum Peckii). Source: B. Freedman.

Video



Revisiting Tla-o-qui-aht Tribal Parks, the Guardians tend to the Intergenerational gardens, which include the largest intact ancient coastal rainforest on Vancouver Island, as profiled in this 7-minute video.
Question after watching: What aspects of sustainability are practiced in Tia-o-qui-aht Tribal Parks?

Environmental Citizenship

Although each of us individually has a relatively small effect on the environment, our collective influence is enormous. If all Canadians were to pursue a lifestyle that has gentler environmental effects, there would be great benefits for all of us, for future generations, and for other species.

Environmental citizenship involves actions that are taken by people and families to lessen their impact on the environment. Individual acts of environmentalism involve making lifestyle choices that include having a small family, using less energy and material resources, and causing less damage to the natural world. In addition to the many sustainability actions that people can undertake, they can give moral and financial support to ENGOs that deal with environmental issues at international, national, and regional levels.

Libraries, bookstores, and websites offer many so-called sustainability handbooks and tools. These list hundreds of specific actions that people and families can take to lessen their effect on the environment. The diverse possibilities include shutting off the lights when leaving a room, turning the thermostat down to 15°C or less during the winter (while layering clothing), avoiding wasteful travel habits (such as commuting alone in a car), avoiding the use of pesticides in lawn and garden care, planting native trees to store carbon on one's property and to provide wildlife habitat, becoming a vegetarian, and giving money and volunteer time to environmental charities (Figure 5.4.4.2).



Figure 5.4.4.2: Each of us can choose to adopt a lifestyle that is less intensive in terms of its environmental impact. This can involve many appropriate choices, such as commuting by bicycle instead of by automobile. (Paul Krueger; CC-BY-2.0)

However, few individual Canadians will make *all* of the sustainable choices that are possible. To do so would be to voluntarily adopt an austere lifestyle, and most people are unwilling or unable to choose this. Instead, most will undertake some positive actions, perhaps including recycling many household wastes, riding a bicycle to school or work, not worrying about a weedy lawn, and favoring several environmental organizations. This would be selective environmentalism rather than a fully green lifestyle. However, if selective environmentalism is substantial enough, and is adopted by many people, there will be huge benefits. Each of us is responsible for demonstrating our environmental citizenship by making as many green choices as possible and by encouraging relatives, friends, and acquaintances to do the same.

If the citizens of Canada and other countries do not make these sensible, environmentally-conscious choices, the results will eventually be tragic.

Things You Can Do to Be More Sustainable

1. **"Reduce energy use**
   Adopt energy-saving habits. Make it a habit to turn off the lights as you leave a room. Also, replace standard light bulbs with energy-efficient compact fluorescent bulbs. Turn off your computer and unplug electronics when they are not in use.
2. **Change the way you think about transportation**
   Walk or bike whenever possible. Not only will you reduce your carbon footprint, but your overall level of health will improve and you will save money on parking and gasoline.

Take public transit or carpool whenever possible.
When purchasing a vehicle look for one with better mileage. Increase your fuel economy when driving by sticking to posted speed limits and avoiding rapid acceleration and excessive braking. Plan and combine trips and errands. This will save you both time and money as well as reduce wear and tear on your vehicle. When travelling long distances, try to take a train or bus rather than flying or driving.

3. **Insulate your home**
   Insulate yourself and your home. By properly insulating your home, you can ensure that heat stays in or out depending on the season. You can do this by purchasing windows and window coverings that will block out or keep in warmth, and by sealing any existing cracks. In winter, reduce your thermostat by 2 °C to enjoy energy savings and a cozy sweater. In summer, use fans to circulate air, and set air conditioners to make your home a comfortable temperature. Lowering the temperature on your water heater to between 55 and 60 °C and insulating your pipes also makes a difference.
4. **Make every drop count**
   Conserve water by fixing drips and leaks, and by installing low-flow shower heads and toilets. Challenge yourself to a speed shower. Turn off water while brushing teeth or shaving. Treating and transporting water requires energy, while water conservation results in reduced energy requirements and carbon emissions.
5. **Cool wash and hang to dry**
   These are not just washing instructions on a label anymore, but an equation for energy savings. Wash clothing in cold water and hang clothing to dry outside, or indoors on a drying rack. Taking these steps will reduce your electricity bill and also prolong the life of clothing by reducing wear on the fabric caused by dryers.
6. **High efficiency appliances**
   When replacing appliances, look for high efficiency units. Appliances with ENERGY STAR ratings, an international standard for energy-efficient consumer products, typically utilize a minimum of 20 % less energy. This means savings for you and the environment.
7. **Switch to "green power"**
   Research where your power is coming from - wind, water, coal, or solar - and talk to your power provider to determine if a greater percentage could be coming from renewable resources. Encourage power providers to switch to green power and, if possible and/or economically viable, switch to a company offering power from renewable resources.
8. **Recycle**
   Make recycling part of your daily routine. Recycle all packaging and consumer goods that you can. Aim to purchase items with minimal and recyclable packaging. For certain items with large amounts of packaging, ask retailers if they can recycle or re-use it. For electronics, facilities now exist that can dispose of electronics in an environmentally responsible manner.
9. **Repurpose**
   Rather than discarding or recycling clothing and household goods, give them a chance at a second life. Gently used clothing can be donated to charity or exchanged with friends and family. Old T-shirts can be repurposed into rags for cleaning. Household goods can be donated to charity or sold at a garage sale. Through repurposing, the amount of waste being sent to landfill sites is reduced, there is no need to use energy for recycling, and others can benefit from your used items.
10. **Plants, our new best friend**
    When gardening, select plants that are well suited to your climate and require minimal watering and attention. Better yet, plant a tree, and it will provide shade and soak up carbon from the atmosphere."

Find more tips here: https://oceans.ubc.ca/about/sustainability-well-being/sustainability-tips/

Source: Government of Canada. 2015. "Things You Can Do to Help the Environment." [Internet] Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/things-you-can-do-help-environment.html

Environmental Literacy

Environmental literacy refers to a well-informed understanding of environmental issues, and it is an important societal goal. Knowledge about the causes and consequences of environmental damage can influence the decisions and choices made by politicians, regulators, corporations, and individual citizens. If appropriate, those decisions and choices can influence environmental quality in a positive way (Figure 5.4.4.3). People acquire this knowledge in various ways, the most important of which are through environmental reporting and other forms of education.

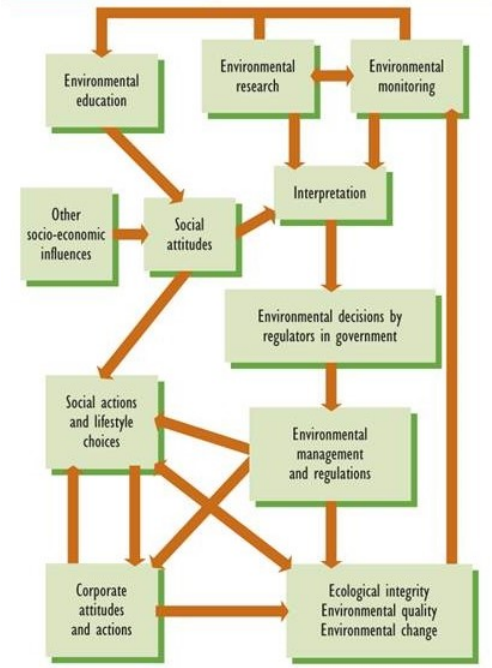


Figure 5.4.4.3: Influences on Environmental Quality. This is a conceptual model of the many influences on environmental quality, including the roles of monitoring, research, regulation, and literacy. Environmental monitoring and research provide an understanding of the causes and consequences of changes in conditions. Ideally, this understanding is based on objective information from monitoring and research programs, interpreted by environmental scientists and other qualified specialists (although their explanations may be conditioned by social and cultural influences). This knowledge is communicated to decision makers in government, who may implement regulations and undertake management activities that affect environmental quality.

Knowledge about environmental and ecological changes is also communicated to the general public, through state-of-the-environment reporting, the educational system, activities of non-governmental organizations, and the mass media. Social attitudes regarding the environment are affected by environmental literacy, and they may result in more appropriate choices of lifestyle and a public influence on the policies and actions of governments and corporations. Environmental literacy has a pervasive influence on the attitudes that people develop. Individuals who are knowledgeable about environmental issues are more likely to make appropriate lifestyle choices and to influence decision-makers to ensure that sensible policies are implemented.

Most people become informed about environmental issues through the mass media, such as the internet, newspapers, and television. These can be effective means of environmental education, but there are drawbacks. Often, media presentations of issues are biased, and sometimes they are inaccurate. The focus is often on controversy, especially when there are unresolved issues that are characterized by scientific uncertainty. This can result in high-profile disputes dominating the environmental agenda, which can detract from efforts to deal with some other important problems whose causation and resolution are better known.

To some degree, this approach can be counterbalanced by providing the broader public with more objective information and by fostering a better understanding of the issues. One means of accomplishing this is to ensure that environmental issues are dealt with, adequately and objectively, in the education system. Ideally, this exposure would occur throughout the system – from primary and high schools, through colleges and universities, to continuing education for the working public.

In contrast, poorly informed public opinion encourages less-appropriate environmental choices, such as rampant consumerism and the wasteful use of natural resources. Environmental illiteracy also fosters the development of controversial “red herrings”, or illogical beliefs that mislead or distract from important issues. An example of an environmental red herring is the common misunderstanding that many people have of the differences between contamination and pollution. Related unhelpful syndromes are known as NIMBY (not in my backyard), LULU (locally unacceptable land use), BANANA (build absolutely nothing anywhere near anybody), and NIMTO (not in my term of office). NIMBY, LULU, and BANANA are common views that many people have about proposed developments that may affect their local environment, while NIMTO is a frequent political response. These attitudes can result, in part, from a lack of credible information about the risks that may be associated with developments in the neighborhood. Alternatively, NIMBY, LULU, and BANANA may result when planners and developers are insensitive to the legitimate concerns of local people.

In addition to affecting the siting of commercial and industrial facilities, NIMBY, LULU, BANANA, and NIMTO cause huge problems for planners who are attempting to build certain kinds of environmental management facilities that society wants and needs. For example, even though all voters recognize that their community needs facilities for the disposal of solid wastes and the treatment of sewage, not many people wish to have such works located in their own neighborhood often leading to environmental injustice.

Sustainable Living

Sustainable living describes a lifestyle that attempts to reduce/eliminate an individual's (or society's) use of resources so as to be as close as possible to "net zero living". As such, an individual (or society) focuses on reducing their footprint (ecologically, carbon, socially, etc) through their choices/methods of:

- Use of resources (energy/food and food waste/transportation/water/etc)
- Support of people/companies (voting/economic/social/etc)
- Practices of reducing, reusing, and recycling
- Consciousness of priority and focus on local concerns/needs versus global concerns/needs
- Sharing knowledge with their community (all ages)

The thought of getting started with sustainable living can be overwhelming. However, it is important to note that although we can acknowledge all the things that need to be accomplished, that the entire burden does not lie with just one individual's control (Figure 5.4.4.4). In fact, most of the changes will need to take place a higher levels of policy and economic decision-making. Overall, it is a multi-layered approach to action at the individual, societal, and political levels that will lead towards true sustainability and it is still possible that these changes can be made for both humans and nature alike.

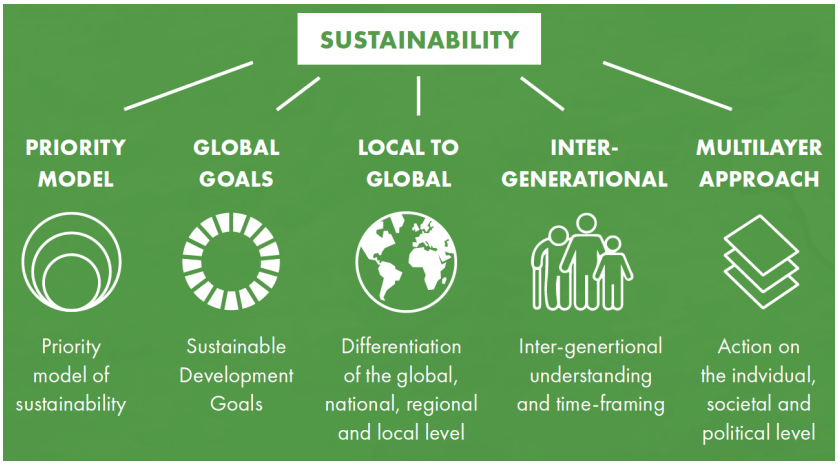


Figure 5.4.4.4: Considerations for sustainable living goals. Image by Sustainability Week Switzerland in Wikimedia Commons (CC-BY-SA)

Video



In this 14-minute second video from 2018, Green shares his analysis on the steps each country has (or has not) made toward these Sustainable Development Goals -- and offers new ideas on what needs to change so we can achieve them by 2030.

Why does Green use the Social Progress Index to measure the SDGs? What does his data tell us? What is a drawback to his method?

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CHAPTER OVERVIEW

2. The Physical Environment

2.1: The Lithosphere
2.2: The Atmosphere
2.3: The Hydrosphere

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2.1: The Lithosphere

EARTH'S FORMATION AND STRUCTURE

The earth formed approximately 4.6 billion years ago from a nebular cloud of dust and gas that surrounded the sun. As the gas cooled, more solids formed. The dusty material accreted to the nebular midplane where it formed progressively larger clumps. Eventually, bodies of several kilometers in diameter formed; these are known as **planetesimals**. The largest planetesimals grew fastest, at the expense of the smaller ones. This process continued until an earth-sized planet had formed.

Early in its formation, the earth must have been completely molten. The main source of heat at that time was probably the decay of naturally-occurring radioactive elements. As the earth cooled, density differences between the forming minerals caused the interior to become differentiated into three concentric zones: the crust, mantle and core. The crust extends downward from the surface to an average depth of 35 km where the mantle begins. The mantle extends down to a depth of 2900 km where the core begins. The core extends down to the center of the earth, a depth of about 6400 km from the surface.

The **core** makes up 16 percent of the volume of the earth and about 31 percent of the mass. It can be divided into two regions: a solid inner core and a liquid outer core. The inner core is probably mostly metallic iron alloyed with a small amount of nickel, as its density is somewhat greater than that of pure metallic iron. The outer core is similar in composition, but probably also contains small amounts of lighter elements, such as sulfur and oxygen, because its density is slightly less than that of pure metallic iron. The presence of the lighter elements depresses the freezing point and is probably responsible for the outer core's liquid state.

The **mantle** is the largest layer in the earth, making up about 82 percent of the volume and 68 percent of the mass of the earth. The mantle is dominated by magnesium and iron-rich (mafic) minerals. Heat from the core of the earth is transported to the crustal region by large-scale convection in the mantle. Near the top of the mantle is a region of partially melted rock called the **asthenosphere**. Numerous small-scale convection currents occur here as hot **magma** (i.e., molten rock) rises and cooler magma sinks due to differences in density.

The **crust** is the thinnest layer in the earth, making up only 1 percent of the mass and 2 percent of the volume. Relative to the rest of the earth, the crust is rich in elements such as silicon, aluminum, calcium, sodium and potassium. Crustal materials are very diverse, consisting of more than 2000 minerals. The less dense crust floats upon the mantle in two forms: the **continental crust** and the **oceanic crust**. The oceanic crust, which contains more **mafic minerals** is thinner and denser than the continental crust which contains minerals richer in silicon and aluminum. The thick continental crust has deep buoyant roots that help to support the higher elevations above. The crust contains the mineral resources and the fossil fuels used by humans.





(Just a note that when he says our Earth is cooling off over time, he's referring to the core of the Earth)

GEOLOGIC TIME SCALE

To describe the time relationships between rock formations and fossils, scientists developed a relative **geologic time scale,** in which the Earth's history is divided and subdivided into time divisions. The three eons (**Phanerozoic**, **Proterozoic**, and **Archean**) represent the largest time divisions (measured in billions of years). They, in turn, are subdivided into **Eras**, **Periods,** and **Epochs**. Major discontinuities in the geologic record and in the corresponding biological (fossil) record are chosen as boundary lines between the different time segments. For example, the Cretaceous-Tertiary boundary (65 million years ago) marks a sudden mass extinction of species, including the dinosaurs. Through the use of modern quantitative techniques, certain rocks and organic matter can be accurately dated by measuring the decay of naturally occurring radioactive isotopes. Therefore, absolute ages can be assigned to some parts of the geologic time scale.





THE LITHOSPHERE AND PLATE TECTONICS

The layer of the mantle above the asthenosphere, plus the entire crust, makes up a region called the **lithosphere**. The lithosphere, and therefore, the earth's crust, is not a continuous shell, but is broken into a series of plates that independently "float" upon the asthenosphere, much like a raft on the ocean. These plates are in constant motion, typically moving a few centimeters a year, and are driven by convection in the mantle. The scientific theory that describes this phenomenon is called **plate tectonics**. According to the theory of plate tectonics, the lithosphere comprises some seven major plates and several smaller ones. Because these plates are in constant motion, interactions occur where plate boundaries meet.

A convergent (colliding) plate boundary occurs when two plates collide. If the convergent boundary involves two continental plates, the crust is compressed into high mountain ranges such as the Himalayas. If an oceanic plate and a continental plate collide, the oceanic crust (because it is denser) is subducted under the continental crust. The region where subduction takes place is called a **subduction zone** and usually results in a deep ocean trench, such as the **"Mariana Trench"** in the western Pacific Ocean. The subducted crust melts, and the resultant magma can rise to the surface and form a volcano. A **divergent plate** boundary occurs when two plates move away from each other. Magma upwelling from the mantle region is forced through the resulting cracks, forming new crust. The mid-ocean ridge in the Atlantic Ocean is a region where new crustal material continually forms as plates diverge. Volcanoes can also occur at divergent boundaries. The island of Iceland is an example of such an occurrence. A third type of plate boundary is the **transform boundary**. This occurs when two plates slide past one another. This interaction can build up strain in the adjacent crustal regions, resulting in earthquakes when the strain is released. The San Andreas Fault in California is an example of a transform plate boundary.









GEOLOGICAL DISTURBANCES

Volcanoes

An active **volcano** occurs when **magma** (**molten rock**) reaches the Earth's surface through a crack or vent in the crust. Volcanic activity can involve the extrusion of lava on the surface, the ejection of solid rock and ash, and the release of water vapor or gas (carbon dioxide or sulfur dioxide). Volcanoes commonly occur near plate boundaries where the motion of the plates has created

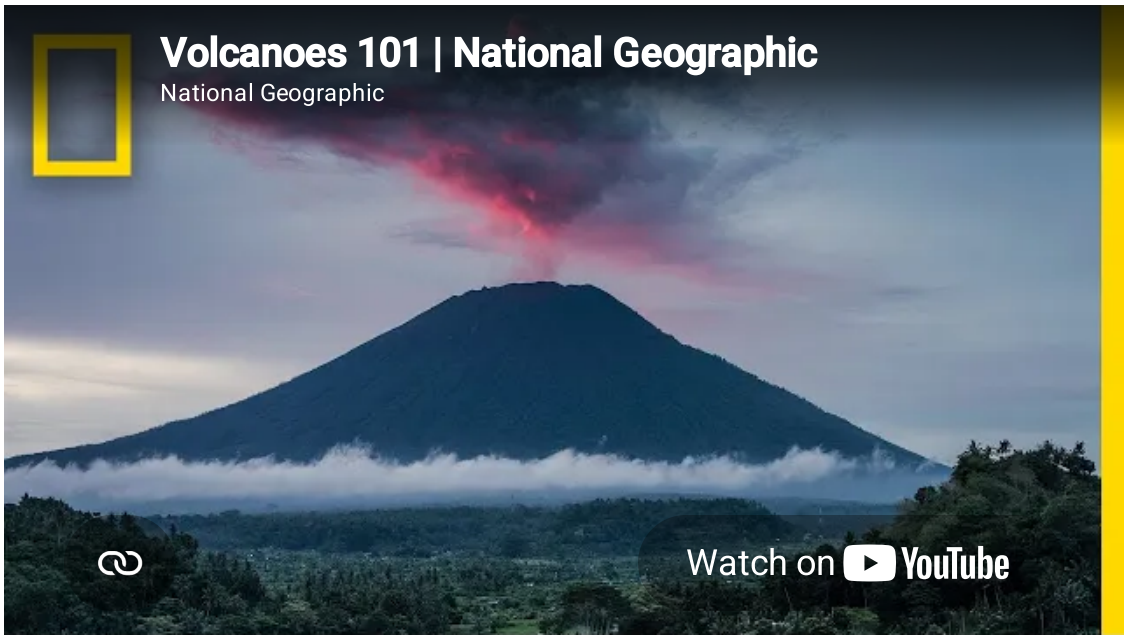
cracks in the lithosphere through which the magma can flow. About eighty percent of volcanoes occur at convergent plate boundaries, where subducted material melts and rises through cracks in the crust. The Cascade Range was formed in this way.

Volcanoes can be classified according to the type and form of their ejecta. The basic types are: composite volcanoes, shield volcanoes, cinder cones, and lava domes. **Composite volcanoes** are steep-sided, symmetrical cones built of multiple layers of viscous lava and ash. Most composite volcanoes have a crater at the summit that contains the central vent. Lavas flow from breaks in the crater wall or from cracks on the flanks of the cone. Mt. Fuji in Japan and Mt. Rainier in Washington are examples of composite volcanoes.

Shield volcanoes are built almost entirely of highly fluid (low viscosity) lava flows. They form slowly from numerous flows that spread out over a wide area from a central vent. The resultant structure is a broad, gently sloping cone with a profile like a warrior's shield. Mt Kilauea in Hawaii is an example of a shield volcano.

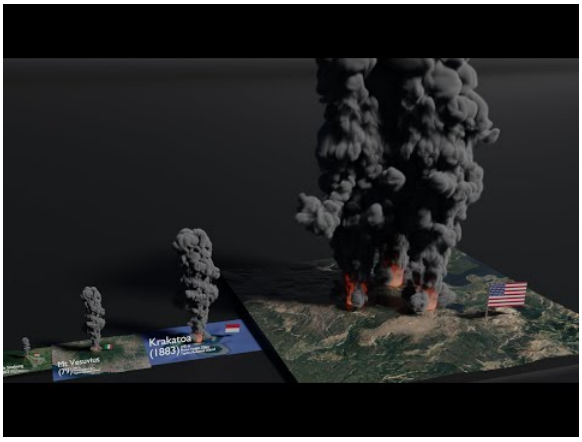
Cinder cones are the simplest type of volcano. They form when lava blown violently into the area breaks into small fragments that solidify and fall as cinders. A steep-sided cone shape is formed around the vent, with a crater at the summit. Sunset Crater in Arizona is a cinder cone that formed less than a thousand years ago, disrupting the lives of the native inhabitants of the region.

Lava domes are formed when highly viscous lava is extruded from a vent and forms a rounded, steep-sided dome. The lava piles up around and on the vent instead of flowing away, mostly growing by expansion from within. Lava domes commonly occur within the craters or on the flanks of composite volcanoes.









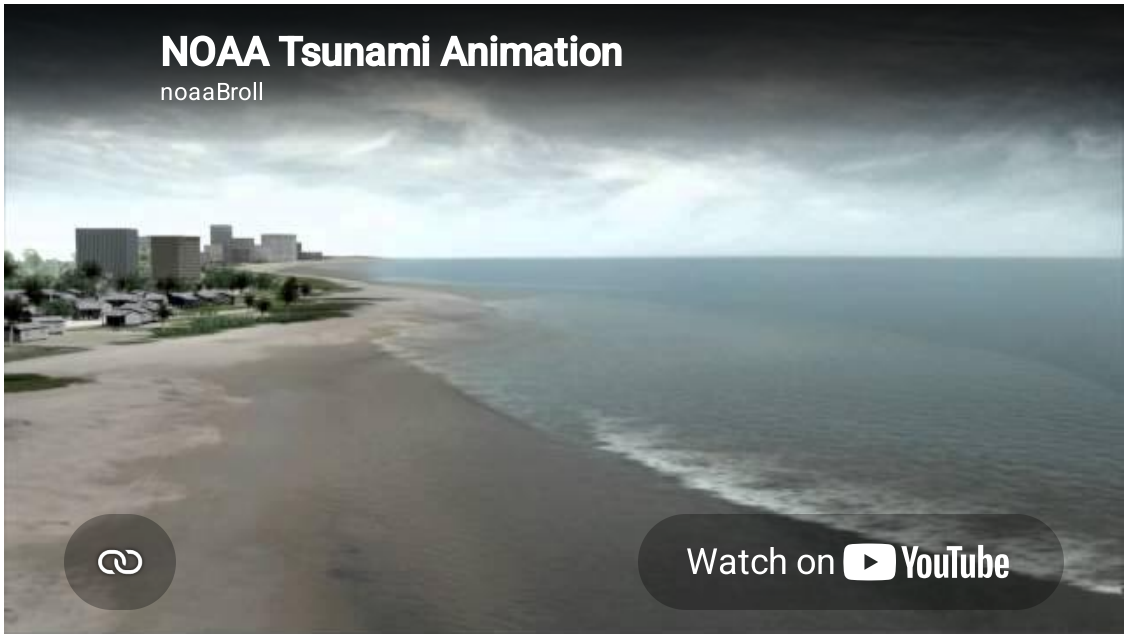
Earthquakes

An **earthquake** occurs when built-up strain in a rock mass causes it to rupture suddenly. The region where the rupture occurs is called the **focus**. This is often deep below the surface of the crust. The point on the surface directly above the focus is called the **epicenter**. Destructive waves propagate outward from the region of the quake, traveling throughout the Earth. The magnitude of an earthquake is a measure of the total amount of energy released. The first step in determining the magnitude is to measure the propagated waves using a device called a **seismograph**. Based on this information, the earthquake is given a number classification on a modified **Richter scale**. The scale is logarithmic, so a difference of one unit means a tenfold difference in wave intensity, which corresponds to an energy difference of 32-fold. The intensity of an earthquake is an indicator of the earthquake's impact at a particular location. The effect depends not only on the magnitude of the earthquake, but also on the types of subsurface materials and the structure and design of surface structures.

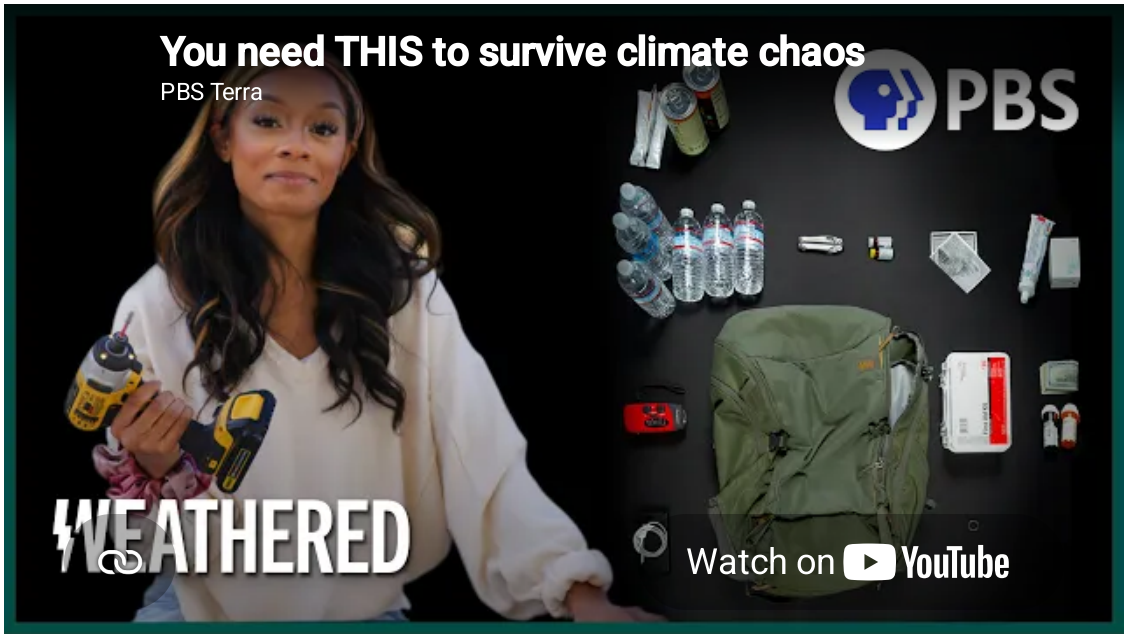
Earthquakes generally occur along breaks in the rock mass known as **faults**, and most occur in regions near plate boundaries. Some 80 percent of all earthquakes occur near convergent plate boundaries, triggered by the interaction of the plates. Earthquakes are also often associated with volcanic activity due to the movement of sub-surface magma. When an earthquake occurs under the ocean, it can trigger a destructive tidal wave known as a **tsunami**.

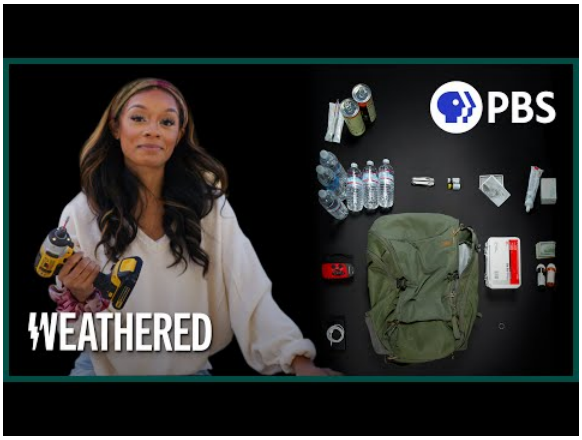

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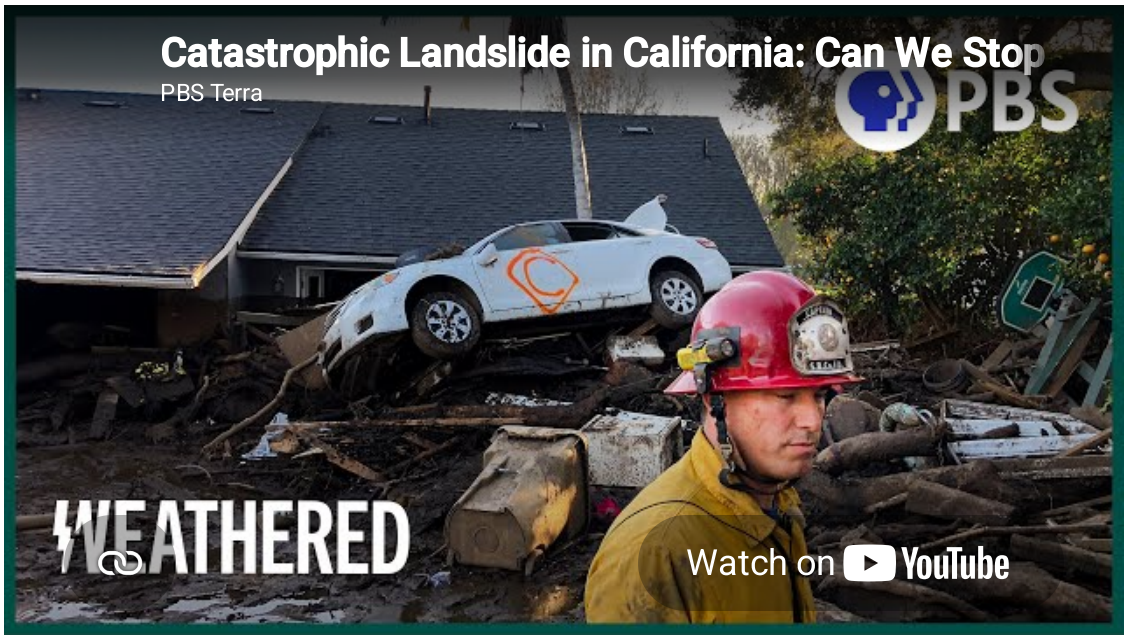


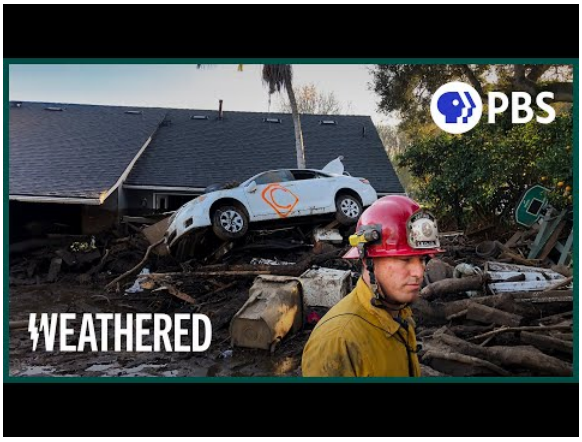

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ROCKS AND THE ROCK CYCLE

The Earth's crust is composed of many kinds of rocks, each of which is made up of one or more minerals. Rocks can be classified into three basic groups: igneous, sedimentary, and metamorphic.

- **Igneous rocks** are the most common rock type found in the Earth's crust. They form when magma cools and crystallizes subsurface (intrusive igneous rocks) or lava cools and crystallizes on the surface (extrusive igneous rocks). Granite is an example of an intrusive igneous rock, whereas basalt is an extrusive igneous rock.
- **Sedimentary rocks** are formed by the consolidation of the weathered fragments of pre-existing rocks, by the precipitation of minerals from solution, or by compaction of the remains of living organisms. The processes involving weathered rock fragments include erosion and transport by wind, water, or ice, followed by deposition as sediments. As the sediments accumulate over time, those at the bottom are compacted. They are cemented by minerals precipitated from solution and become rocks.
    - The process of compaction and cementation is known as **lithification**. Some common types of sedimentary rocks are limestone, shale, and sandstone. Gypsum represents a sedimentary rock precipitated from solution. Fossil fuels such as coal and oil shale are sedimentary rocks formed from organic matter.
- **Metamorphic rocks** are formed when solid igneous, sedimentary, or metamorphic rocks change in response to elevated temperature and pressure and/or chemically active fluids. This alteration usually occurs in the subsurface of the rock. It may involve a change in texture (recrystallization), a change in mineralogy, or both. Marble is a metamorphosed form of limestone, while slate is transformed shale. Anthracite is a metamorphic form of coal.

The **rock cycle** illustrates connections between the Earth's internal and external processes and how the three basic rock groups are related to one another. Internal processes include melting and metamorphism due to elevated temperature and pressure. Convective currents in the mantle keep the crust in constant motion (plate tectonics). Buried rocks are brought to the surface (uplift), and surface rocks and sediments are transported to the upper mantle region (subduction).

Two important external processes in the rock cycle are **weathering** and **erosion**.

- Weathering is the process by which rock materials are broken down into smaller pieces and/or chemically changed.
- Once rock materials are broken down into smaller pieces, they can be transported elsewhere in a process called erosion. The main vehicle of erosion is moving water, but wind and glaciers can also erode rock.





SOILS and SOIL FORMATION

Soil is one of the Earth's most precious and delicate resources. Its formation involves the weathering of parent materials (e.g., rocks) and biological activity. Soil has four principal components: water, eroded inorganic parent material, air, and organic matter (e.g., living and decaying organisms).

Soil formation begins with unconsolidated materials that are the products of **weathering**. These materials may be transported to the location of soil formation by processes such as wind or water, or may result from the weathering of underlying bedrock. The weathering process involves the disintegration and decomposition of the rock. It can be physical (e.g., water seeping into rock cracks and then freezing) or chemical (e.g., dissolution of minerals by acid rain). Physical processes are more prevalent in cold and dry climates, while chemical processes are more prevalent in warm or moist climates.

Soil materials tend to move vertically in the formation environment. Organic materials (e.g., leaf litter) and sediments can be added, while other materials (e.g., minerals) can be lost due to erosion and leaching. Living organisms (e.g., bacteria, fungi, worms, and insects) also become incorporated into the developing soil.

The living component of the soil breaks down other organic materials to release their nutrients (e.g., nitrogen, potassium, and phosphorus). The nutrients are then used and recycled by growing plants and other organisms. This recycling of nutrients helps create and maintain a viable soil.

Several factors influence soil formation, including: climate, parent material, biologic organisms, topography, and time. The climate of an area (precipitation and temperature) may be the most important factor in soil formation. Temperature affects the rates of

chemical reactions, and rainfall affects soil pH and leaching. Parent material or bedrock varies from region to region and can affect the texture and pH of soils. Vegetation type affects the rate at which nutrients in the soil are recycled, the type and amount of organic matter in the soil, soil erosion, and the types and numbers of microorganisms living in the soil.

Humans can also have a profound effect on soils through such activities as plowing, irrigating, and mining. The topography of a region affects rainfall runoff, erosion and solar energy intake. Soil formation is a continuous process. Soils change with time as factors such as organic matter input and mineral content change. The process of making a soil suitable for use by humans can take tens of thousands of years. Unfortunately, the destruction of that soil can occur in a few short generations.

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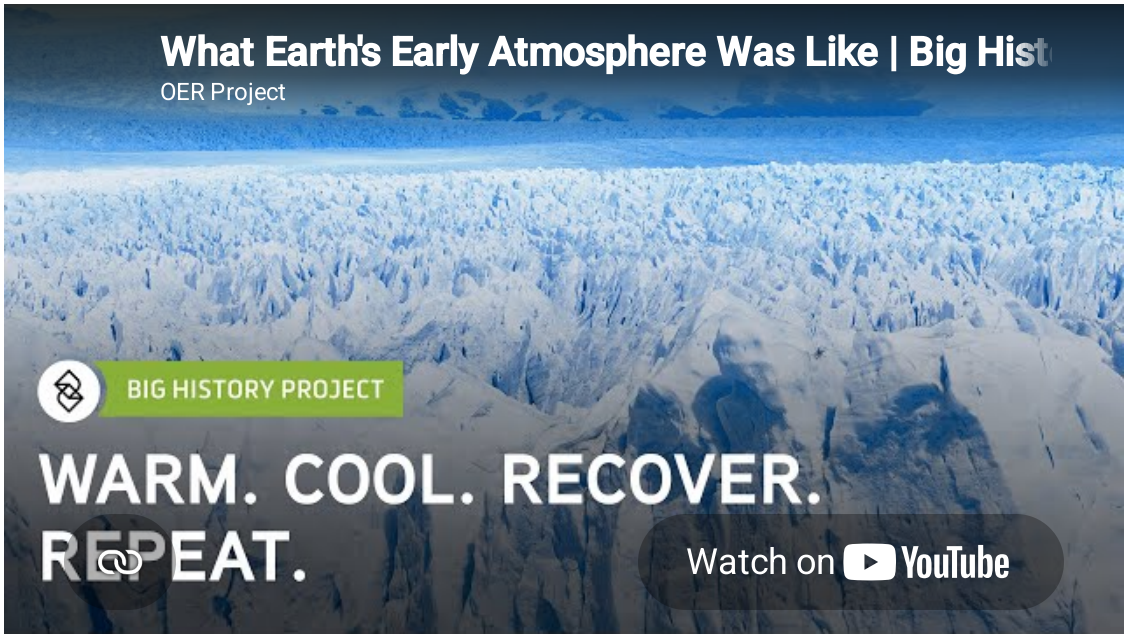
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2.2: The Atmosphere

INTRODUCTION

The **atmosphere**, the gaseous layer that surrounds the Earth, formed more than **four billion** years ago. During the evolution of the solid Earth, volcanic eruptions released gases into the developing atmosphere. Assuming the gases released were similar to those of modern volcanoes, the gases released included: water vapor (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), hydrochloric acid (HCl), methane (CH_4), ammonia (NH_3), nitrogen (N_2), and sulfur gases. The atmosphere was reducing because there was no free oxygen. Most of the hydrogen and helium released would have eventually escaped into outer space due to the inability of the Earth's gravity to hold on to their small masses. There may have also been significant contributions of volatiles from the massive meteoritic bombardments known to have occurred early in the Earth's history.

Water vapor in the atmosphere condensed and rained down, eventually forming lakes and oceans. The oceans provided homes for the earliest organisms, which were probably similar to cyanobacteria. Oxygen was released into the atmosphere by these early organisms, and carbon became sequestered in sedimentary rocks. This led to our current oxidizing atmosphere, which is mostly comprised of nitrogen (roughly 71 percent) and oxygen (roughly 28 percent). Water vapor, argon, and carbon dioxide together comprise a much smaller fraction (roughly 1 percent). The atmosphere also contains several gases in trace amounts, such as helium, neon, methane, and nitrous oxide. One very important trace gas is ozone, which absorbs harmful UV radiation from the sun.





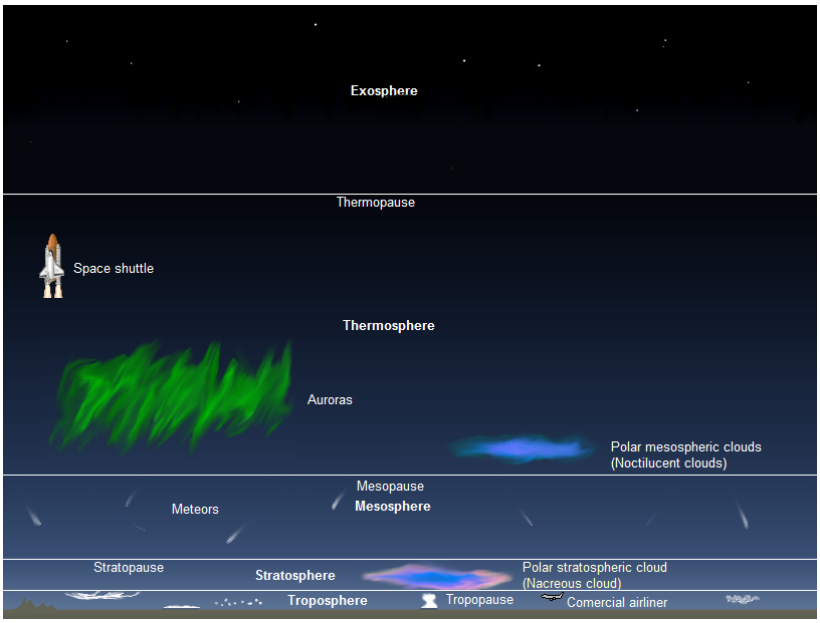
ATMOSPHERIC STRUCTURE

This information will come up again when learning about climate change, but it is important to understand the basic structure of the modern Earth's atmosphere first.

The Earth's atmosphere, which is very thin compared to Earth, extends outward to about 1,000 kilometers, where it transitions to interplanetary space. However, most of the mass of the atmosphere (greater than 99 percent) is located within the first 40 kilometers. The sun and the Earth are the main sources of radiant energy in the atmosphere. The sun's radiation spans the infrared, visible, and ultraviolet light regions, while the Earth's radiation is mostly infrared.

Solar radiation is the main energy source for atmospheric heating. The atmosphere heats up when water vapor and other greenhouse gases in the troposphere absorb infrared radiation either directly from the sun or re-radiated from the earth's surface. Heat from the sun also evaporates ocean water and transfers heat to the atmosphere. The Earth's surface temperature varies with latitude. This is due to uneven heating of the Earth's surface. The region near the equator receives direct sunlight, whereas sunlight strikes the higher latitudes at an angle and is scattered and spread out over a larger area. The angle at which sunlight strikes the higher latitudes varies during the year due to the fact that the Earth's equatorial plane is tilted 23.5º relative to its orbital plane around the sun. This variation is responsible for the different seasons experienced by the non-equatorial latitudes.

The vertical temperature profile of the atmosphere is variable and depends upon the types of radiation that affect each atmospheric layer. This, in turn, depends upon the chemical composition of that layer (mostly involving trace gases). Based on these factors, the atmosphere can be divided into four distinct layers: the troposphere, stratosphere, mesosphere, and thermosphere.



Troposphere

The **troposphere** is the atmospheric layer closest to the Earth's surface. It extends about 8 - 16 kilometers from the Earth's surface. The thickness of the layer varies a few km according to latitude and the season of the year. It is thicker near the equator and during the summer, and thinner near the poles and during the winter. The troposphere contains the largest percentage of the mass of the atmosphere relative to the other layers. It also contains about 99 percent of the total water vapor of the atmosphere.

The temperature of the troposphere is warm (roughly 17ºC) near the surface of the Earth. This is due to the absorption of infrared radiation from the surface by water vapor and other greenhouse gases (e.g., carbon dioxide, nitrous oxide, and methane) in the troposphere. The concentration of these gases decreases with altitude, and therefore, the heating effect is greatest near the surface. The temperature in the troposphere decreases at a rate of roughly 6.5ºC per kilometer of altitude. The temperature at its upper boundary is very cold (roughly -60ºC).

Because hot air rises and cold air falls, there is a constant convective overturn of material in the troposphere. Indeed, the name troposphere means “region of mixing.” For this reason, all weather phenomena occur in the troposphere. Water vapor evaporated

from the earth's surface condenses in the cooler upper regions of the troposphere and falls back to the surface as rain. Dust and pollutants injected into the troposphere become well mixed in the layer, but are eventually washed out by rainfall. The troposphere is therefore self-cleaning.

Tropopause

A narrow zone at the top of the troposphere is called the **tropopause**. It effectively separates the underlying troposphere and the overlying stratosphere. The temperature in the tropopause is relatively constant. Strong eastward winds, known as the **jet stream**, also occur here.

Stratosphere

The **stratosphere** is the next major atmospheric layer. This layer extends from the tropopause (roughly 12 kilometers) to roughly 50 kilometers above the Earth's surface. The temperature profile of the stratosphere is quite different from that of the troposphere. The temperature remains relatively constant up to roughly 25 kilometers and then gradually increases up to the upper boundary of the layer. The amount of water vapor in the stratosphere is very low, so it is not an important factor in the temperature regulation of the layer. Instead, it is ozone (O3) that causes the observed temperature inversion.

Because the temperature of the stratosphere rises with altitude, there is little convective mixing of the gases. The stratosphere is therefore very stable. Particles that are injected (such as volcanic ash) can stay aloft for many years without returning to the ground. The same is true for pollutants produced by humans.

Ozone Layer

Most of the ozone in the atmosphere is contained in a layer of the stratosphere from roughly 20 to 30 kilometers. This ozone layer absorbs solar energy in the form of ultraviolet radiation (UV), and the energy is ultimately dissipated as heat in the stratosphere. This heat leads to a rise in temperature. Stratospheric ozone is also very important for living organisms on the surface of the Earth, as it protects them by absorbing most of the harmful UV radiation from the sun. Ozone is constantly being produced and destroyed in the stratosphere in natural cycles. Most of the production and destruction of ozone occurs in the stratosphere at lower latitudes where the ultraviolet radiation is most intense.

Ozone is very unstable and is readily destroyed by reactions with other atmospheric species such as nitrogen, hydrogen, bromine, and chlorine. In fact, most ozone is destroyed in this way. The use of **chlorofluorocarbons (CFCs)** by humans in recent decades has greatly affected the natural ozone layer by increasing the rate of its destruction due to reactions with chlorine.

Stratopause and Mesosphere

The upper boundary of the stratosphere is known as the **stratopause**, which is marked by a sudden decrease in temperature.

The third layer in the Earth's atmosphere is called the **mesosphere**. It extends from the stratopause (about 50 kilometers) to roughly 85 kilometers above the Earth's surface. Because the mesosphere has negligible amounts of water vapor and ozone for generating heat, the temperature drops across this layer. It is warmed from the bottom by the stratosphere. The air is very thin in this region, with a density about 1/1000 that of the surface. With increasing altitude, this layer becomes increasingly dominated by lighter gases, and in the outer reaches, the remaining gases become stratified by molecular weight.

Thermosphere

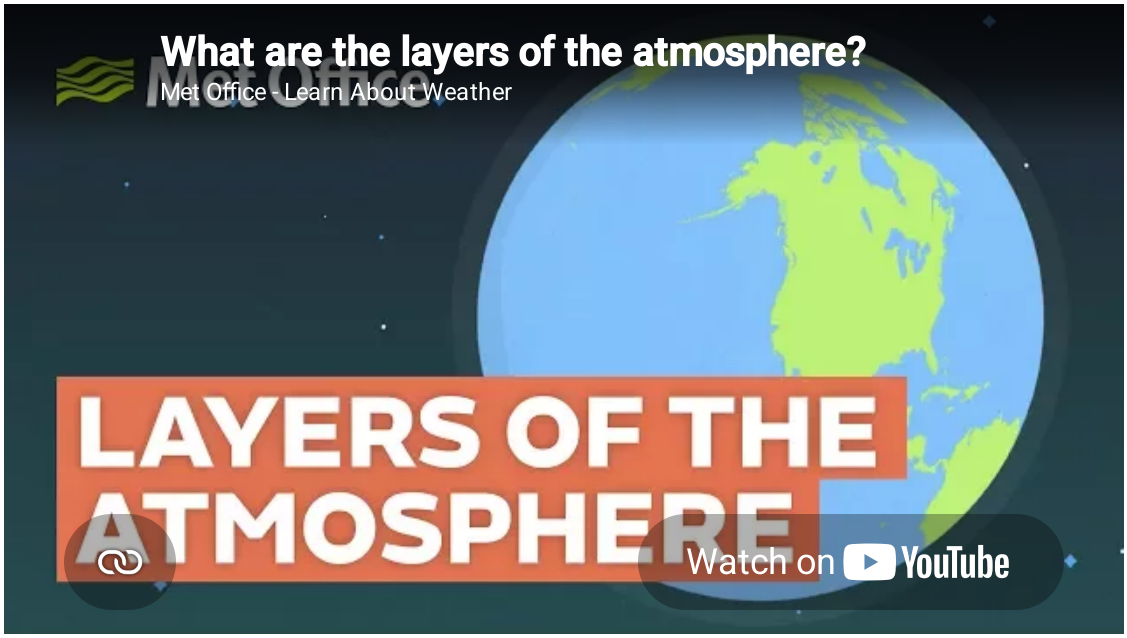
The fourth layer, the **thermosphere**, extends outward from about 85 kilometers to about 600 kilometers. Its upper boundary is ill-defined. The temperature in the thermosphere increases with altitude to greater than 1500ºC. The high temperatures are the result of absorption of intense solar radiation by the last remaining oxygen molecules. The temperature can vary substantially depending on the level of solar activity.

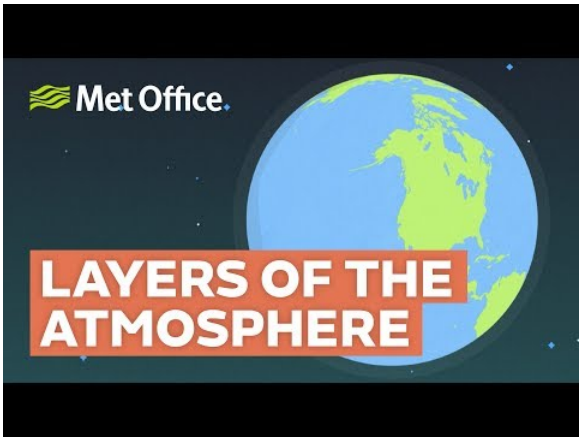
Ionosphere

The lower region of the thermosphere (up to about 550 kilometers) is also known as the **ionosphere**. Because of the high temperatures in this region, gas particles become ionized. The ionosphere is important because it reflects radio waves from the Earth's surface, allowing long-distance radio communication. The visual atmospheric phenomenon known as the northern lights also occurs in this region.

Exosphere

The outer region of the atmosphere is known as the **exosphere**. The exosphere represents the final transition between the atmosphere and interplanetary space. It extends about 1000 kilometers and contains mainly helium and hydrogen. Most satellites operate in this region.





COMPONENTS OF THE DYNAMIC ATMOSPHERE

Wind

Convecting air masses in the troposphere create air currents known as **winds**, due to horizontal differences in air pressure. Winds flow from a region of higher pressure to one of lower pressure. Global air movement begins in the equatorial region because it receives more solar radiation. The general flow of air from the equator to the poles and back is disrupted, though, by the rotation of the Earth. The Earth's surface travels faster beneath the atmosphere at the equator and slower at the poles. This causes air masses moving to the north to be deflected to the right, and air masses moving south to be deflected to the left. This is known as the "**Coriolis Effect**." The result is the creation of six huge **convection cells** situated at different latitudes. Belts of prevailing surface winds form and distribute air and moisture over the earth.

Jet streams are extremely strong bands of wind that form in or near the tropopause due to large air pressure differentials. Wind speeds can reach as high as 200 kilometers per hour. In North America, there are two main jet streams: the polar jet stream, which occurs between the westerlies and the polar easterlies, and the subtropical jet stream, which occurs between the trade winds and the westerlies.

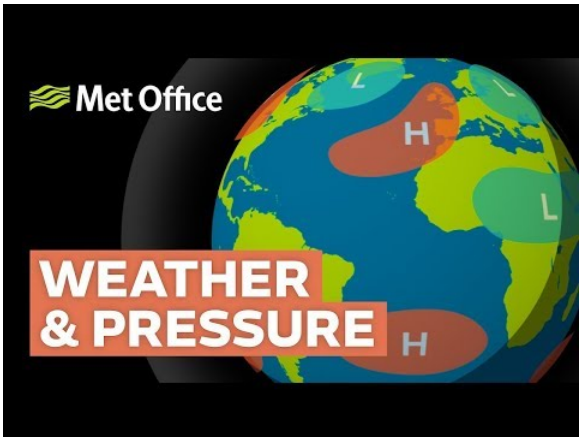




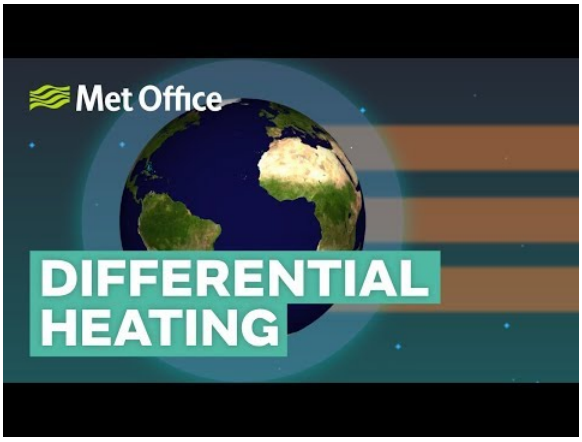
Weather

The term **weather** refers to the short-term changes in the physical characteristics of the troposphere. These physical characteristics include: temperature, air pressure, humidity, precipitation, cloud cover, wind speed, and direction. Radiant energy from the sun is the power source for weather. It drives the convective mixing in the troposphere, which determines the atmospheric and surface weather conditions.


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Probably the most important part of the weather is **precipitation, such** as rainfall or snowfall. Water from the vast salty oceans evaporates and falls over land as fresh water. It is rainfall that provides fresh water for land plants and land animals. Winter snowfall in mountainous regions provides a stored supply of fresh water, which melts and flows into streams during the spring and summer.

Atmospheric clouds are the generators of precipitation. Clouds form when a rising air mass cools and the temperature and humidity are right for condensation to occur. Condensation does not occur spontaneously, but instead requires a **condensation nucleus**. These are tiny (less than 1µm) dust or smoke particles. The condensation droplet is small enough (about 20 µm) that it is supported by the atmosphere against the pull of gravity. The visible result of these condensation droplets is a cloud.

Under the right conditions, droplets may continue to grow by continued condensation onto the droplet and/or coalescence with other droplets through collisions. When the droplets become sufficiently large, they begin to fall as precipitation. Typical raindrops are about 2 mm in diameter. Depending upon the temperature of the cloud and the temperature profile of the atmosphere from the cloud to the earth's surface, various types of precipitation can occur: rain, freezing rain, sleet, or snow. Very strong storms can produce relatively large chunks of ice called **hailstones**.

ATMOSPHERIC DISTURBANCES

Certain atmospheric conditions can lead to extreme weather phenomena such as thunderstorms, floods, tornadoes, and hurricanes.

Thunderstorms

A **thunderstorm** forms in a region of atmospheric instability, often occurring at the boundary between cold and warm fronts. Warm, moist air rises rapidly (updraft) while cooler air flows down to the surface (downdraft). Thunderstorms produce intense rainfall, lightning, and thunder. If the atmospheric instability is very large and there is a large increase in wind strength with altitude (vertical wind shear), the thunderstorm may become severe. A severe thunderstorm can produce flash floods, hail, violent surface winds, and tornadoes.


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Floods

Floods can occur when atmospheric conditions allow a storm to remain in a given area for a length of time, or when a severe thunderstorm dumps very large amounts of rainfall in a short time period. When the ground becomes saturated with water, the excess runoff flows into low-lying areas or rivers and causes flooding.






The Catastrophic Flood That Triggered an Ice Age
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Tornadoes

A **tornado** begins in a severe thunderstorm. Vertical wind shear causes the updraft in the storm to rotate and form a funnel. The rotational wind speeds increase, and vertical stretching occurs due to angular momentum. As air is drawn into the funnel core, it cools rapidly and condenses to form a visible funnel cloud. The funnel cloud descends to the surface as more air is drawn in. Wind speeds in tornadoes can reach several hundred miles per hour. Tornadoes are most prevalent in the Great Plains region of the United States, forming when cold, dry polar air from Canada collides with warm, moist tropical air from the Gulf of Mexico.

Tornadoes are measured on the Enhanced Fujia Scale from EF0-EF5

EF Rating	Wind Speeds	Expected Damage	
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.	
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.	
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.	
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.	
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.	
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.	


How are tornadoes formed?
Met Office - Learn About Weather
HOW ARE TORNADOES FORMED?
Watch on YouTube


HOW ARE TORNADOES FORMED?


Tornadoes 101 | National Geographic
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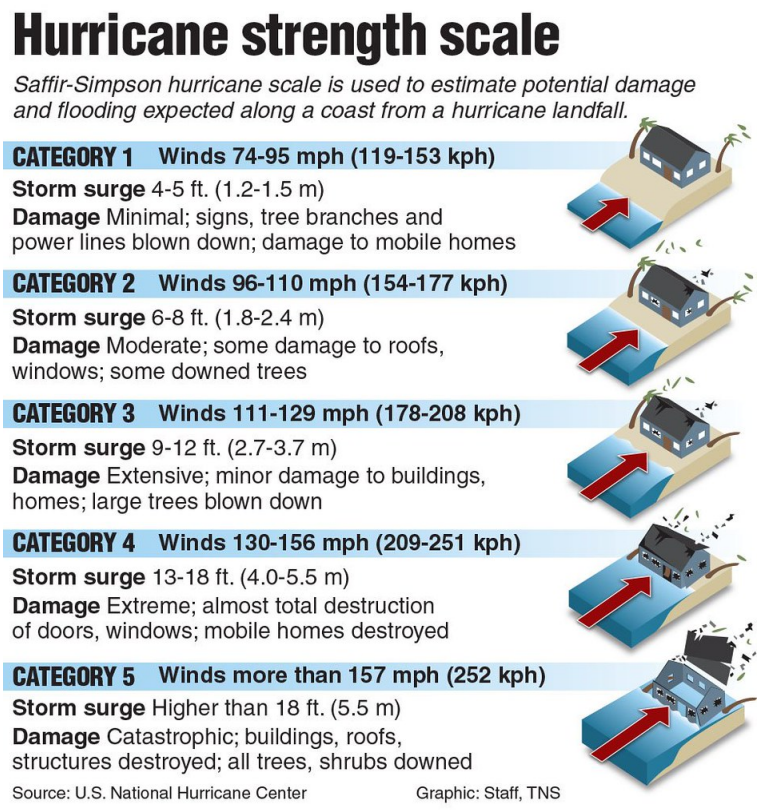


Cyclone, Hurricanes, and Typhoons

A **cyclone** is an area of low pressure with winds blowing counterclockwise (Northern Hemisphere) or clockwise (Southern Hemisphere) around it. Tropical cyclones are given different names depending on their wind speed. Cyclonic storms with wind speed exceeds 74 miles per hour are named by the ocean body they arise in: **hurricanes** in the Atlantic Ocean, **typhoons** in the Pacific Ocean, and **cyclones** in the Indian Ocean.

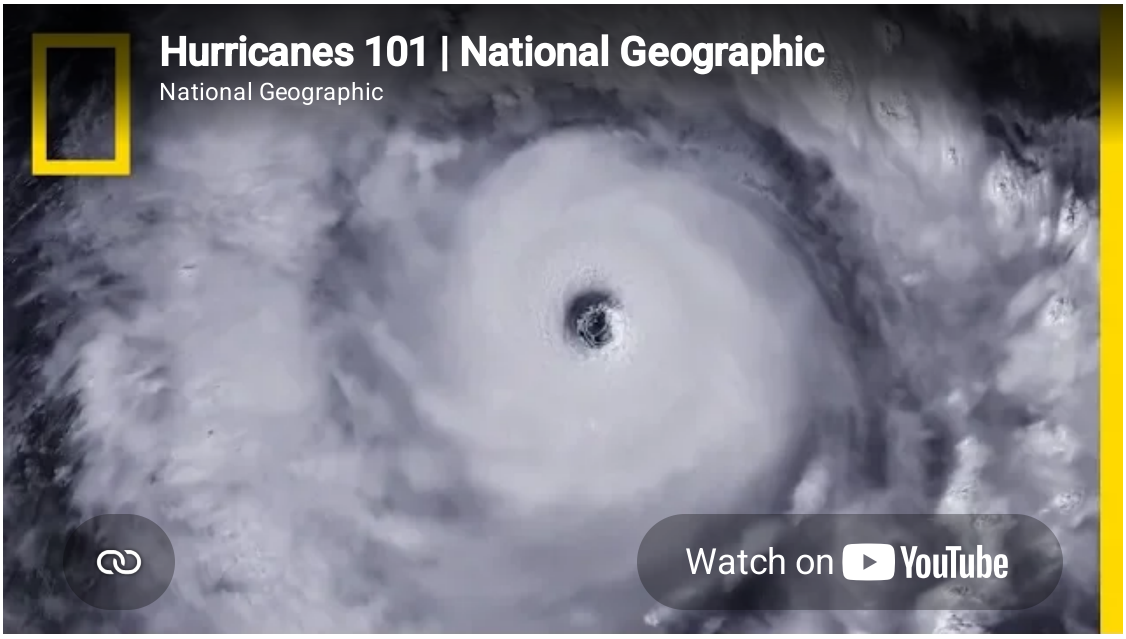
Hurricanes are the most powerful of all weather systems, characterized by strong winds and heavy rain over wide areas. They form over the warm tropical ocean and quickly lose intensity when they move over land. Hurricanes affecting the continental United States generally occur from June through November.

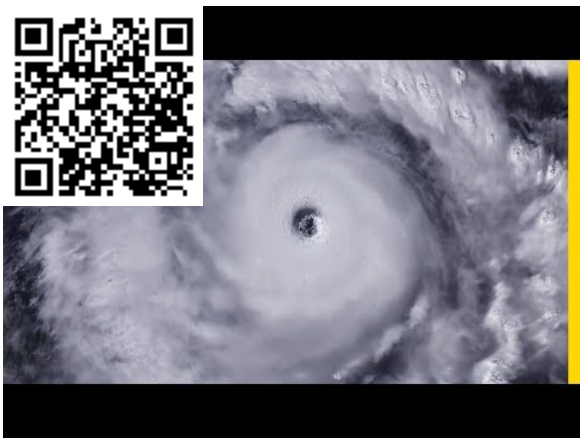
Hurricanes are categorized on the Saffir-Simpson Scale from Category 1 to Category 5.






HURRICANES,
TYPHOONS
& CYCLONES

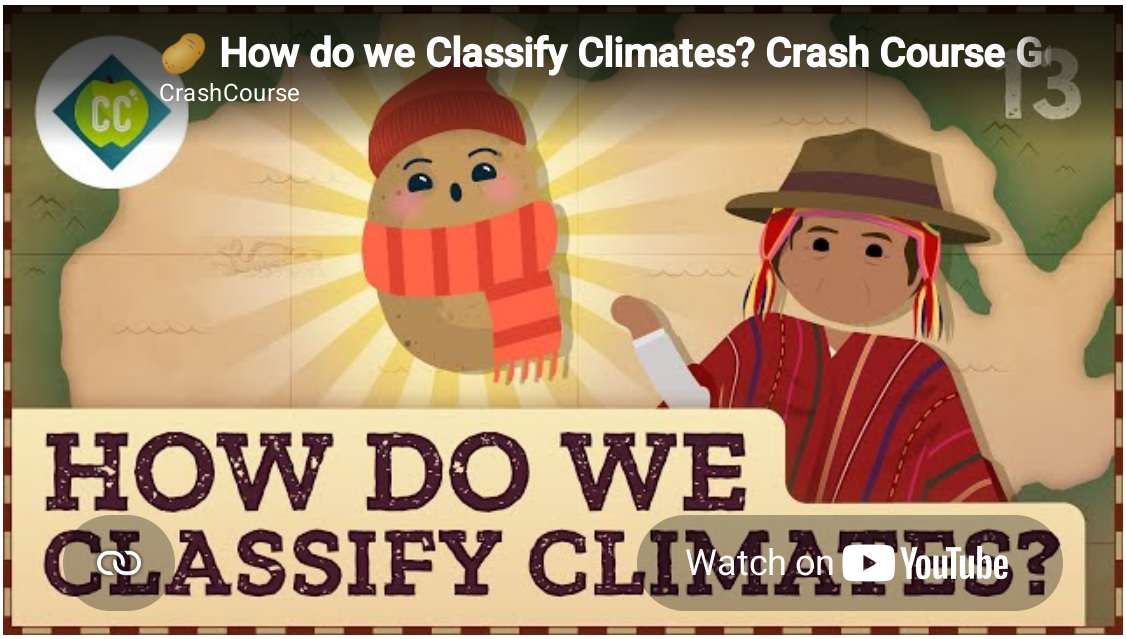

Hurricanes 101 | National Geographic
National Geographic
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Climate can be thought of as a measure of a region's average weather over a period of time. In defining a climate, the geography and size of the region must be taken into account. A micro-climate might involve a backyard in the city. A macroclimate might cover a group of states. When the entire earth is involved, it is a global climate. Several factors control large-scale climates, such as latitude (solar radiation intensity), distribution of land and water, pattern of prevailing winds, heat exchange by ocean currents, location of global high and low pressure regions, altitude, and location of mountain barriers.





The most widely used scheme for classifying climate is the **Köppen System**. This scheme uses average annual and monthly temperature and precipitation to define five climate types:

1.	tropical moist climates: average monthly temperature is always greater than 18°C
2.	dry climates: deficient precipitation most of the year
3.	moist mid-latitude climates with mild winters
4.	moist mid-latitude climates with severe winters
5.	polar climates: extremely cold winters and summers.

Using the Köppen system and the seasonal dominance of large scale air masses (e.g., maritime or continental), the earth's climate zones can be grouped as follows:

1.	tropical wet
2.	tropical wet and dry
3.	tropical desert
4.	mid-latitude wet
5.	mid-latitude dry summer
6.	mid-latitude dry winter
7.	polar wet
8.	dry and polar desert

Los Angeles has a mid-latitude dry summer climate, whereas New Orleans has a mid-latitude wet climate.

Data from natural climate records (e.g., ocean sediments, tree rings, Antarctic ice cores) show that the Earth's climate constantly changed in the past, with alternating periods of colder and warmer climates. The most recent ice age ended only about 10,000 years ago. The natural system controlling the climate is very complex. It consists of a large number of feedback mechanisms that involve processes and interactions within and between the atmosphere, biosphere, and the solid earth.

Some of the historical causes of global climate change include plate tectonics (landmass and ocean current changes), volcanic activity (atmospheric dust and greenhouse gases), and long-term variations in the Earth's orbit and the angle of its rotation axis (absolute and spatial variations in solar radiation).

More recently, anthropogenic (human) factors are known to be changing the global climate. Since the late 19th century, the average temperature of the Earth has increased by about 1º °C. This warming trend is the result of the increased release of greenhouse gases (e.g., CO2) into the atmosphere from the combustion of fossil fuels. The science and impacts of climate change will be covered in an upcoming section, but the physical and biological nature of our planet will radically transform if human society does not address the root causes of climate change now. /p>

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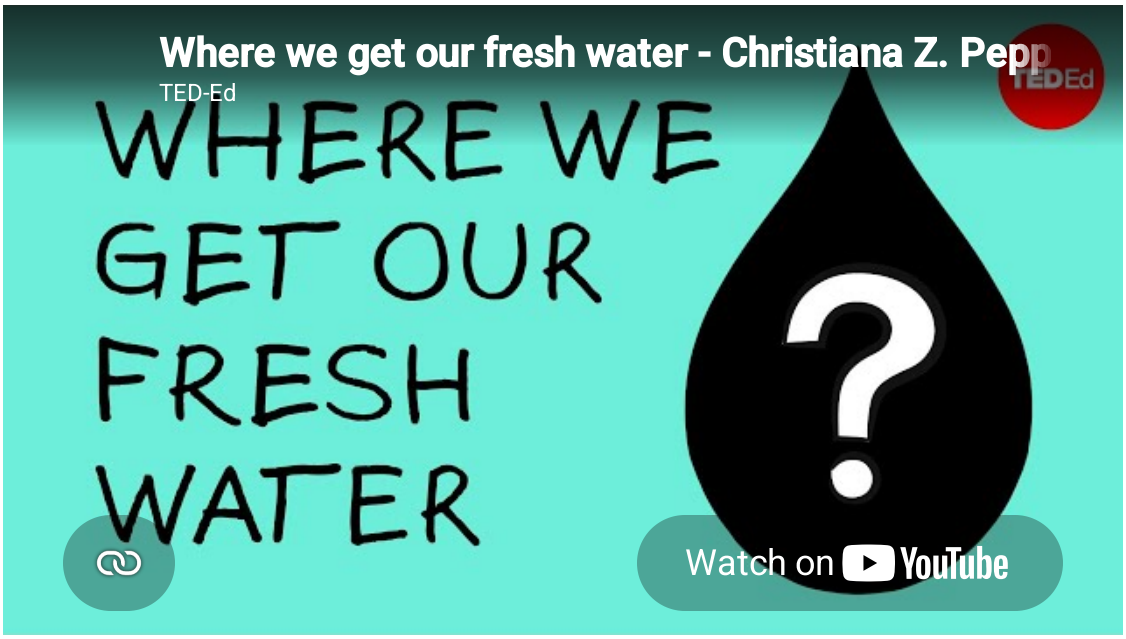
2.3: The Hydrosphere

INTRODUCTION

Water is an abundant substance on Earth and covers 71 percent of the Earth's surface. Earth’s water consists of three percent freshwater and 97 percent saltwater. All living organisms require water to live. In fact, they are mostly comprised of water. Water is also important for other reasons: as an agent of erosion, it changes the morphology of the land; it acts as a buffer against extreme climate changes when present as a large body of water, and it helps flush away and dilute pollutants in the environment.









The physical characteristics of water influence the way life on Earth exists. The unique characteristics of water are:

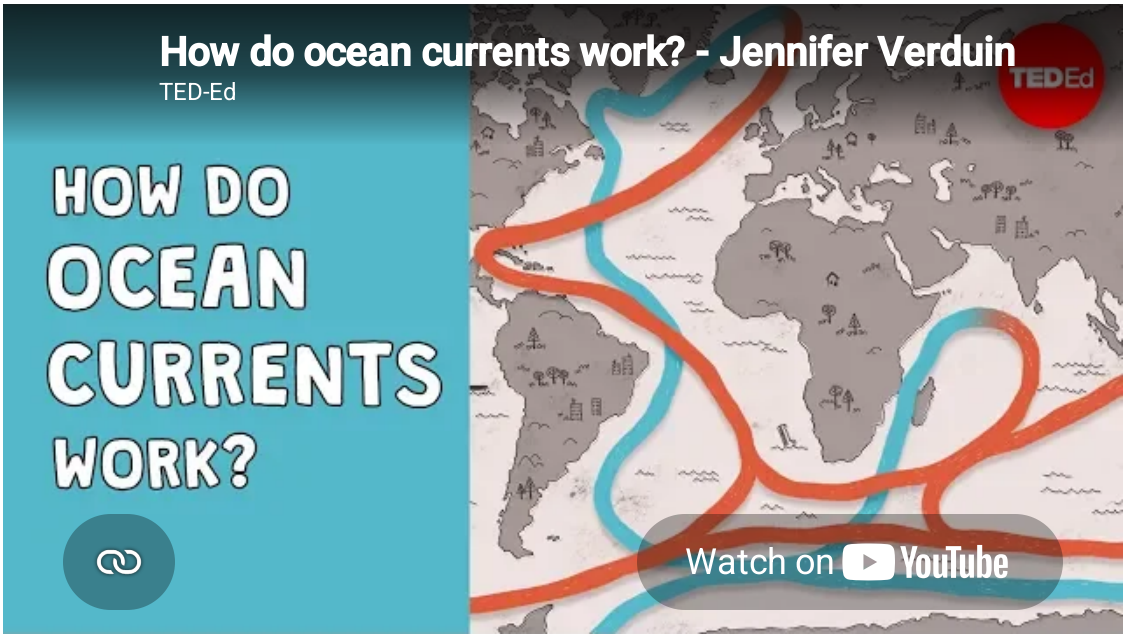
1. Water is a liquid at room temperature and over a relatively wide temperature range (0 -100°C). This wide range encompasses the annual mean temperature of most biological environments.
2. A relatively large amount of energy is required to raise the temperature of water (i.e., it has a high **heat capacity**). As a result of this property, large bodies of water act as buffers against extreme fluctuations in the climate, water makes an excellent industrial coolant, and it helps protect living organisms against sudden temperature changes in the environment.
3. Water has a very high heat of vaporization. Water evaporation helps distribute heat globally; it provides an organism with the means to dissipate unwanted heat.
4. Water is a good solvent and provides a good medium for chemical reactions, including those that are biologically important. Water carries nutrients to an organism's cells and flushes away waste products, and it allows the flow of ions necessary for muscle and nerve functions in animals.
5. Liquid water has a very high **surface tension**, the force holding the liquid surface together. This, along with its ability to adhere to surfaces, enables the upward transport of water in plants and soil by capillary action.
6. Solid water (ice) has a lower density than liquid water at the surface of the Earth. If ice were denser than liquid water, it would sink rather than float, and bodies of water in cold climates would eventually freeze solid, killing the organisms living in them.

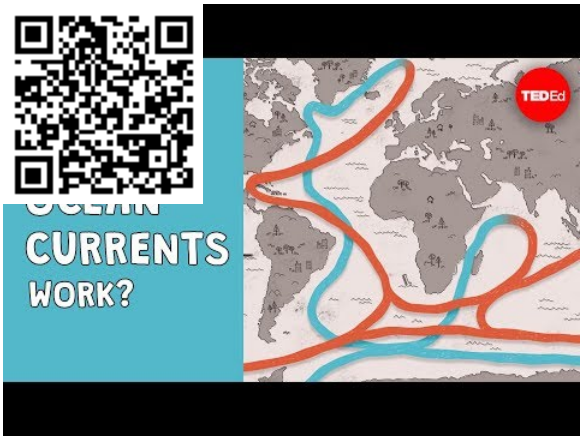
Freshwater comprises only about three percent of the earth's total water supply and is found as either surface water or groundwater. Surface water starts as precipitation. That portion of precipitation that does not infiltrate the ground is called **runoff**. Runoff flows into streams and lakes.

The drainage basin from which water drains is called a **watershed**. Precipitation that infiltrates the ground and becomes trapped in cracks and pores of the soil and rock is called **groundwater**. If groundwater is stopped by an impermeable barrier of rock, it can accumulate until the porous region becomes saturated. The top of this accumulation is known as the **water table**. Porous layers of sand and rock through which groundwater flows are called **aquifers**.

Most freshwater is locked up in frozen glaciers or deep groundwater, where it is not usable by most living organisms. Only a tiny fraction of the earth's total water supply is therefore usable freshwater. Still, the amount available is sufficient to maintain life because of the natural water cycle. In the water cycle, water constantly accumulates, becomes purified, and is redistributed. Unfortunately, as human populations across the globe increase, their activities threaten to overwhelm the natural cycle and degrade the quality of available water.

OCEAN CURRENTS





Since the Earth's surface is over 71 percent water, it is not surprising that oceans have a significant effect on the weather and climate. Because of the high heat capacity of water, the ocean acts as a temperature buffer. That is why coastal climates are less extreme than inland climates. Most of the radiant heat from the sun is absorbed by the ocean surface waters, and ocean currents help distribute this heat.

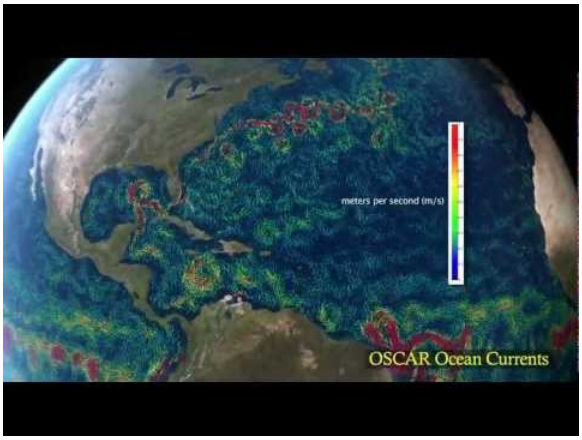
Currents are the movement of water in a predictable pattern. **Surface ocean currents** are driven mostly by prevailing winds. The "Coriolis Effect" causes the currents to flow in circular patterns. These currents help transport heat from the tropics to the higher

latitudes. Two large surface currents near the United States are the California Current along the west coast and the Gulf Stream along the east coast. Differences in water temperature and density drive **deep ocean currents**. They move in a convective pattern.

The less dense (lower salinity) warm water in the equatorial regions rises and moves towards the polar regions, while the more dense (higher salinity) cold water in the polar regions sinks and moves towards the equatorial regions. Sometimes this cold deep water moves back to the surface along a coastline in a process known as **upwelling**. This cold, deep water is rich in nutrients that support productive fishing grounds.

About every three to seven years, warm water from the western equatorial Pacific moves to the eastern equatorial Pacific due to weakened trade winds. The eastern Pacific Ocean thus becomes warmer than usual for a period of about a year. This is known as **El Niño**. El Niño prevents the nutrient-rich, cold-water upwelling along the western coast of South America. It also impacts the global weather conditions. Some regions receive heavier than usual rainfall, while other regions suffer drought conditions with lower than usual rainfall.





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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

3.1: Matter

3.2: Energy

3.3: A Cell is the Smallest Unit of Life

3.4: Energy Enters Ecosystems Through Photosynthesis

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

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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 in nature and less than 30 are found in living cells. Each element possesses unique properties that 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 can bond with oxygen to create a water molecule. Hydrogen atoms cannot be broken down into anything smaller while still retaining the properties of hydrogen. All matter (rocks, stars, or organisms) is made of atoms. Atoms are made of protons and neutrons (which exist in the nucleus of an atom) and electrons (which orbit around an atom).

At the most basic level, all organisms are made of a combination of elements. They contain atoms that combine to form **molecules**. Molecules are chemicals made from two or more atoms **bonded** together. How elements interact with one another depends on the number of electrons and how they are arranged. There are three types of basic bonds: ionic bonds, covalent bonds, and hydrogen bonds.

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.

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 exist on that planet or did previously. 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 as we know it would not exist.

Several important properties of water make it so important to life:

- **Water is polar.** The hydrogen and oxygen atoms within water molecules form bonds that allow each water molecule to attract other water molecules. Water also attracts other polar molecules (such as sugars) that can dissolve in water.
- **Water is an excellent solvent.** Because water is polar, other polar compounds and molecules can readily dissolve in it. Water is, therefore, what is referred to as a solvent—a substance capable of dissolving another substance. This makes it an excellent molecule for transporting substances throughout an organism.
- **Water stabilizes temperature.** The 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 the 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 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**. Water molecules are attracted to each other, 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. 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. Cohesive and

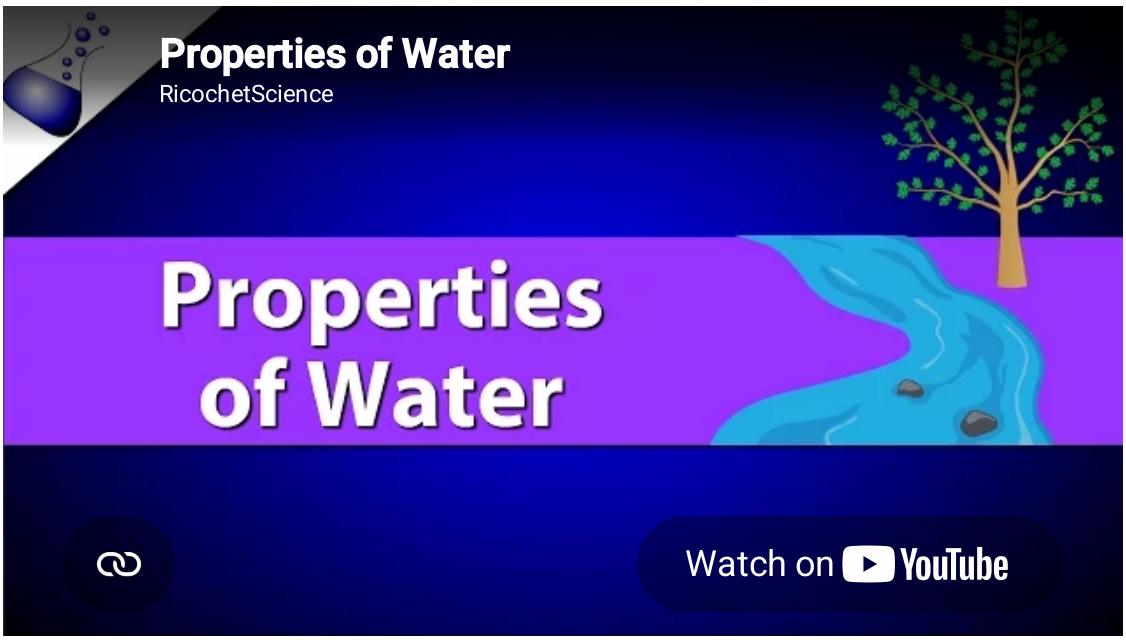
adhesive forces are important for sustaining life. For example, because of these forces, water can flow up from the roots to the tops of plants to feed the plant.






How Do Trees Transport Water from Roots to Leav
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Properties of Water
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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).

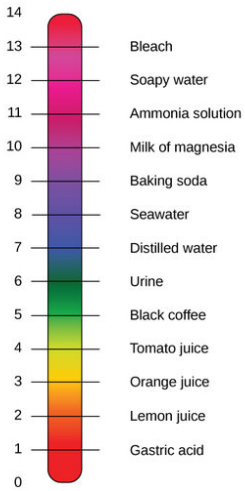
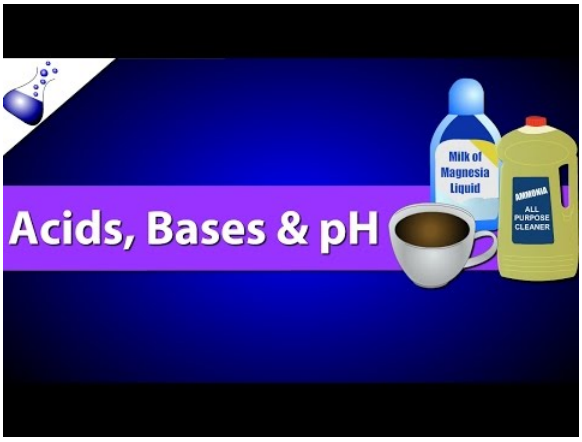


Figure 3.1.4. The pH scale measures the amount of hydrogen ions (H+) in a substance. (credit: modification of work by Edward Stevens)

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. They may also contain oxygen, nitrogen, phosphorus, sulfur, and additional elements. There are four major classes of important organic molecules: **carbohydrates**, **lipids**, **proteins**, and **nucleic acids.** Each 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.

Lipids include a diverse group of compounds that are united by a common feature: they are hydrophobic (“water-fearing”), or insoluble in water, because they are non-polar. Lipids include fats, oils, waxes, phospholipids, and steroids.

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.
- Lipids are also the building blocks of many hormones and are an important constituent of cellular membranes.

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 composed of (polymers of) amino acids. The functions of proteins are very diverse because there are 20 different chemically distinct amino acids that can be combined in any order and in very long strands. Proteins can function as

enzymes, hormones, contractile fibers, cytoskeleton rods, and much more. **Enzymes** are vital to life because they act as catalysts in biochemical reactions (like digestion). Each enzyme is specific for the material (substrate) upon which it acts. Enzymes can function to break molecular bonds, to rearrange bonds, or to form new bonds.

Carbohydrates include sugars and starches. These compounds contain only the elements carbon, hydrogen, and oxygen. Functions of carbohydrates in living things include providing energy to cells, storing energy, and forming certain structures, such as the cell walls of plants. The monomer that makes up large carbohydrate compounds is called a monosaccharide.

Nucleic acids are very large molecules that support 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 the largest trees and mammals, and has a beautiful double-helical structure (Figure 3.1.6). The other type of nucleic acid, **RNA**, is mostly involved in protein synthesis and its regulation. DNA and RNA are made up of small building blocks known as **nucleotides**.

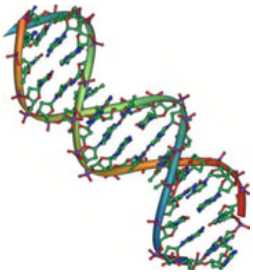
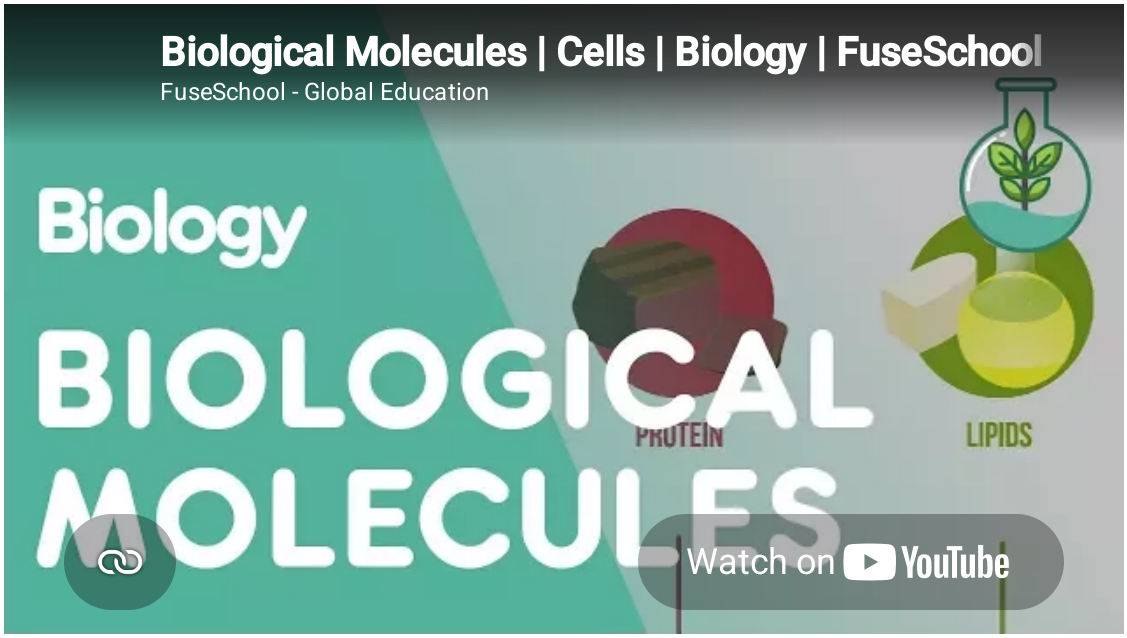


Figure 3.1.6. The double-helix model shows DNA as two parallel strands of intertwining molecules.





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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.

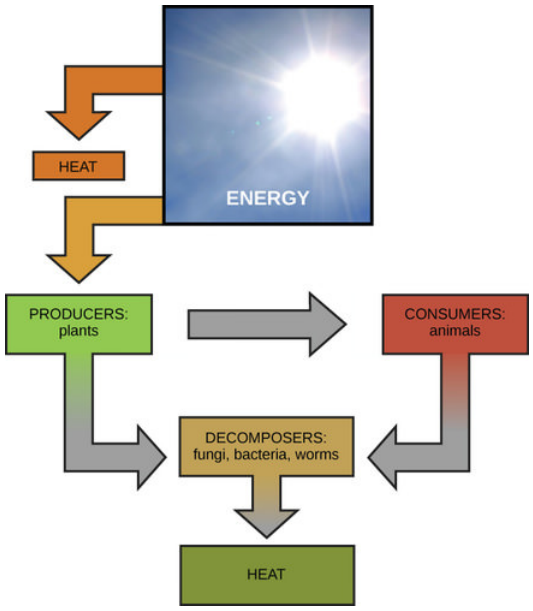


Figure 3.2.1. Ultimately, most life forms get their energy from the sun. Plants use photosynthesis to capture sunlight, and herbivores eat the plants to obtain energy. Carnivores eat the herbivores, and eventual decomposition of plant and animal material contributes to the nutrient pool.

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).

Biological organisms exchange energy 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.

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 or transformed, but it cannot be created or destroyed. 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 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 by transferring and transforming the chemical energy stored in biological molecules via a series of chemical reactions into ATP molecules. Energy in ATP molecules is easily accessible to do work. You can think of ATP like energy cash for the cell free to spend on any work that is needed, like building complex molecules, transporting materials, powering the motion of cilia or flagella, and contracting muscles to create movement.

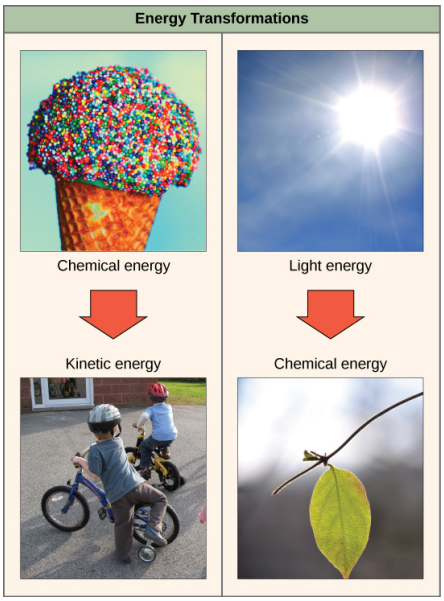


Figure 3.2.2. Shown are some examples of energy transferred and transformed from one system to another and from one form to another. The food we consume provides our cells with the energy required to carry out bodily functions, just as light energy provides plants with the means to create the chemical 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)

The **second law of thermodynamics** explains why obtaining, transforming, and using energy to do work are harder than they appear and why they are never completely efficient. In every energy transfer and transformation, some amount of energy is lost in an unusable form, usually **heat energy.** Heat energy is the energy transferred from one system to another that is not work. For example, heat energy is lost during all cellular metabolic reactions (think of how hot you might get during physical exercise - you are losing heat energy). Therefore, living things must be highly ordered, requiring constant energy input (sunlight or chemicals/food) to be maintaing life as they lose heat to the environment.





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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 3.3.1). 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.

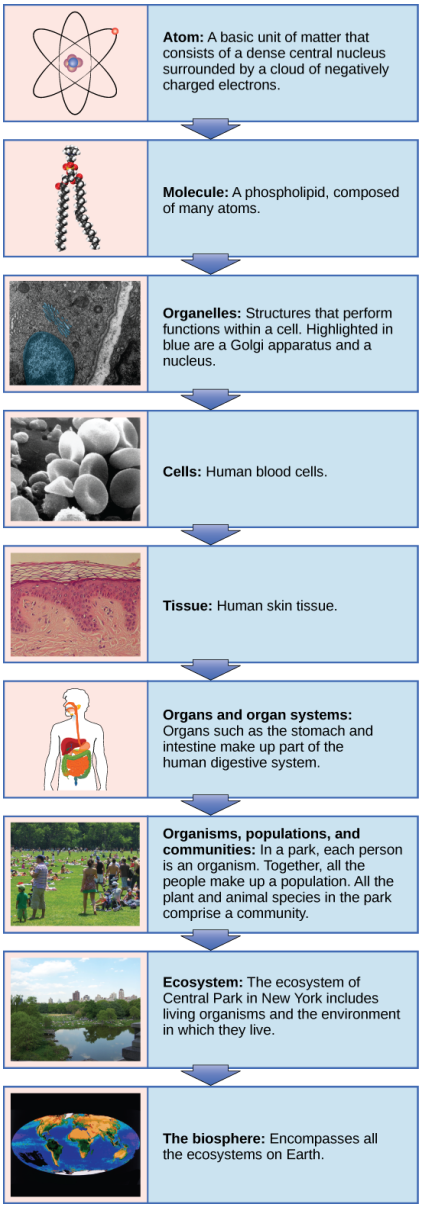
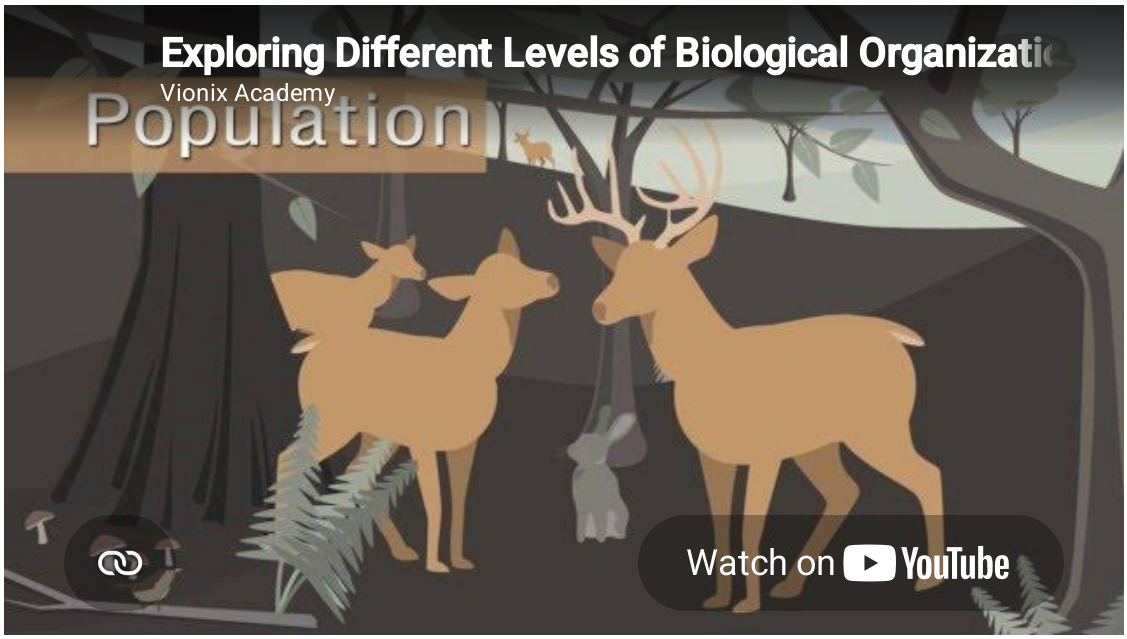


Figure 3.3.1. From an atom to the entire Earth, biology examines all aspects of life. (credit “molecule”: modification of work by Jane Whitney; credit “organelles”: modification of work by Louisa Howard; credit “cells”: modification of work by Bruce Wetzel, Harry Schaefer, National Cancer Institute; 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 made 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.

Important historical advances in understanding cells:

- mid-1600s: Antony van Leeuwenhoek used simple lenses to observe movements of single-celled organisms and sperm, which he collectively termed “animalcules.”
- 1665: Robert Hooke coined the term “cell” (from the Latin *cella*, meaning “small room”) for the box-like structures he observed when viewing cork tissue.
- 1670s: van Leeuwenhoek discovered bacteria and protozoa with more advanced lenses.
- late 1830s, Matthias Schleiden and Theodor Schwann observed tissues with better microscopes 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 (bacteria and archaea) and eukaryotic (animals, plants, fungi, and protists).

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.





Prokaryotic Cells

A **prokaryotic cell** is a simple, single-celled (unicellular) organism that lacks a nucleus, or any other membrane-bound organelle. Prokaryotic DNA is found in the central part of the cell: a darkened region called the nucleoid (Figure 3.3.1).

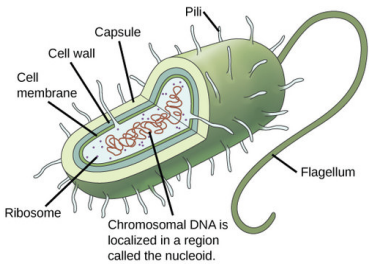


Figure 3.3.2. This figure shows the generalized structure of a prokaryotic cell.

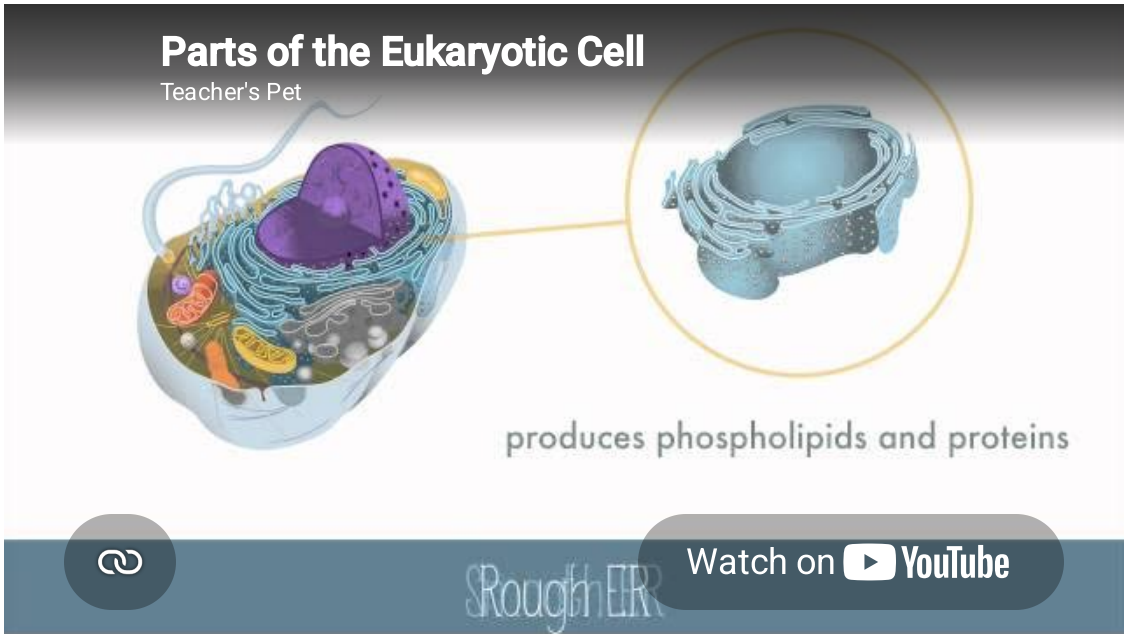
Bacteria and Archaea are different in parts of their cellular structures. Both are very different from eukaryotes and are critical in the functioning of all life. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili are used to exchange genetic material during a type of reproduction called conjugation. Fimbriae are protein appendages used by bacteria to attach to other cells.

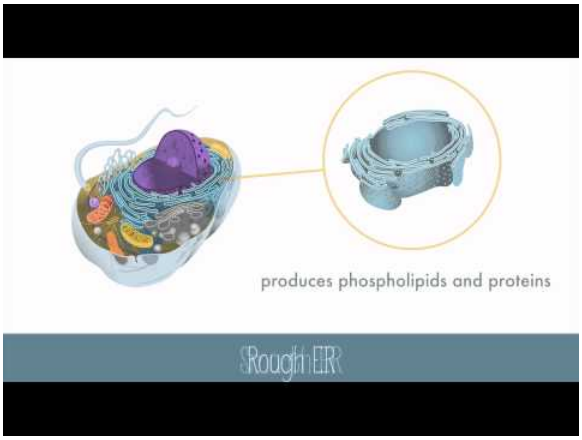




Eukaryotic Cells

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 3.3.3).





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 3.3.3). The small size of prokaryotes allows ions and organic molecules that enter them to spread rapidly 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.

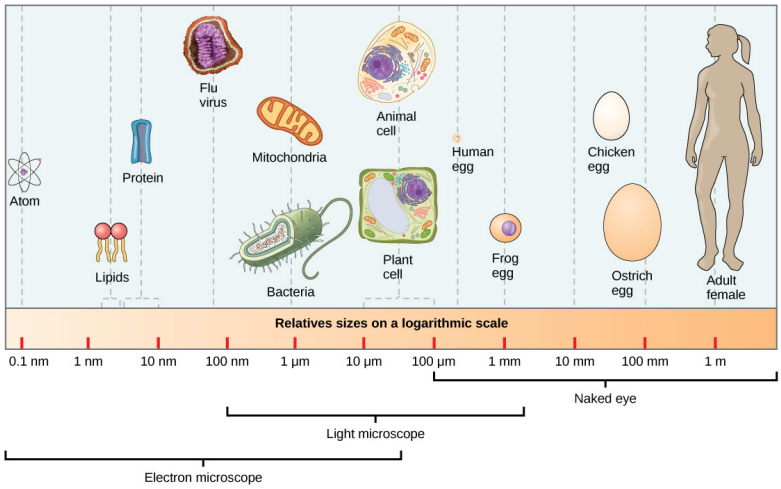


Figure 3.3.3. This figure indicates the relative sizes of various cells and cellular components. An adult human is shown for comparison.

Animal Cells versus Plant Cells

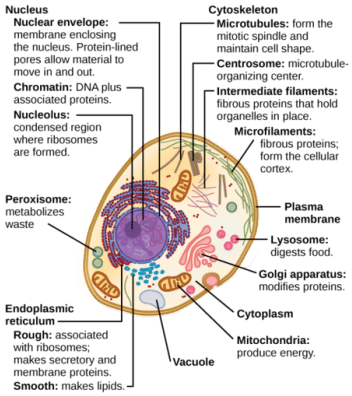


Figure 3.3.4. An example of a typical animal cell.

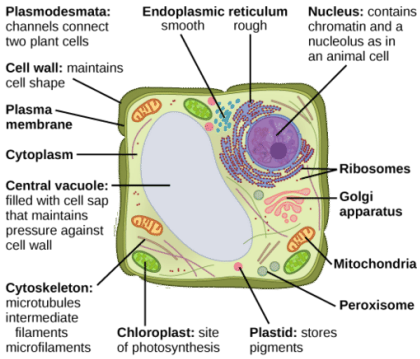


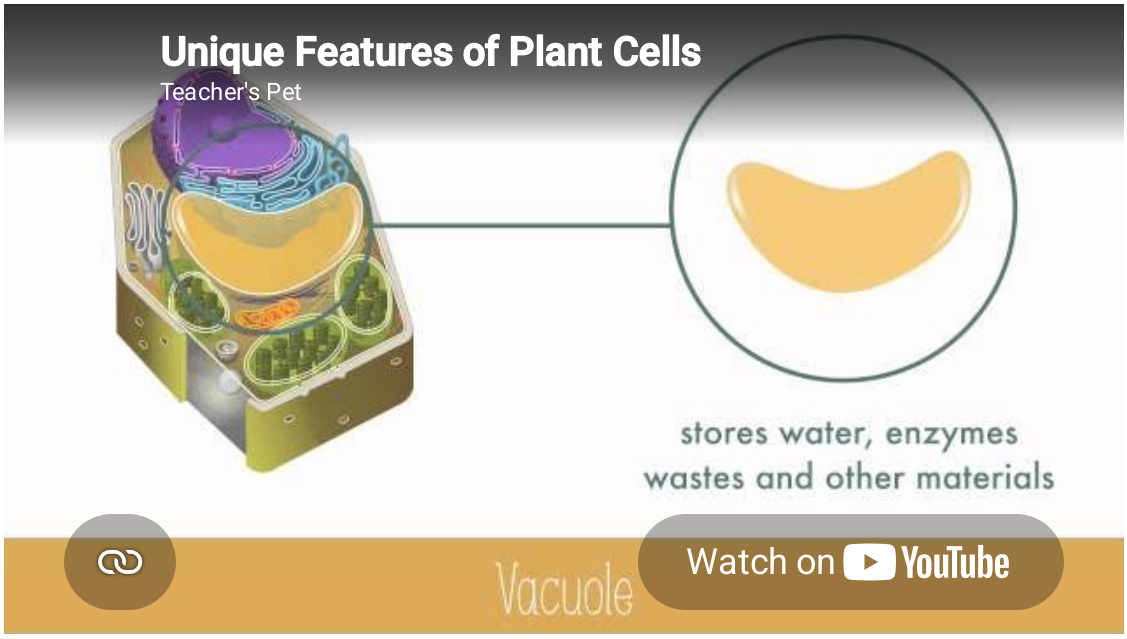
Figure 3.3.5. An example of a typical plant cell.

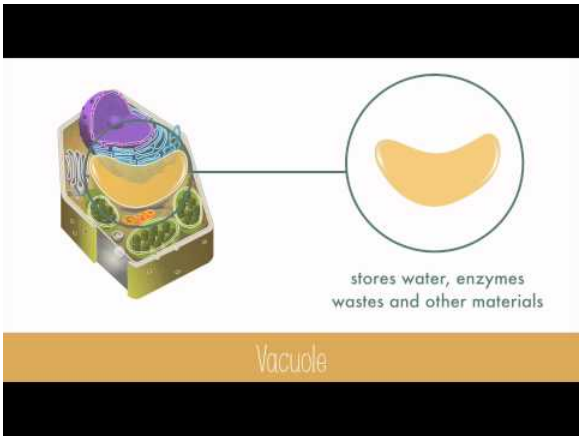
Despite their fundamental similarities, there are some striking differences between animal and plant cells (Figure 3.3.3). Animal cells have centrioles, centrosomes, and lysosomes, whereas plant cells do not. Plant cells have a rigid cell wall that is external to the

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 very 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 can make their own food, like glucose, whereas animals must obtain food by consuming other organisms.





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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



Figure 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 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 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 3.4.2). Using this reasoning, all food eaten by humans can be traced back to autotrophs that carry out photosynthesis.

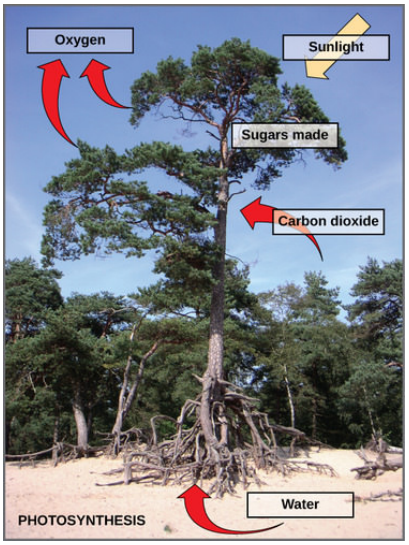


Figure 3.4.3. Photosynthesis uses solar energy, carbon dioxide, and water to release oxygen and to produce energy-storing sugar molecules.

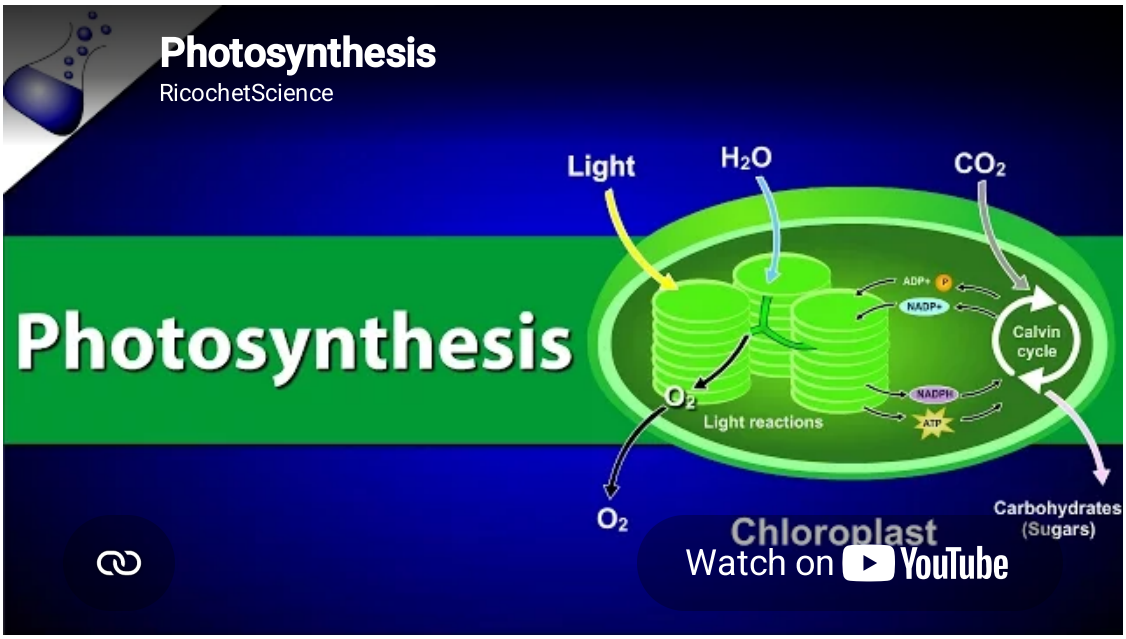
Photosynthesis requires sunlight, carbon dioxide, and water as starting reactants (Figure 3.4.3). After the process is complete, photosynthesis releases oxygen and produces carbohydrate molecules, most commonly glucose. These sugar molecules contain the energy that living things need to survive. The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

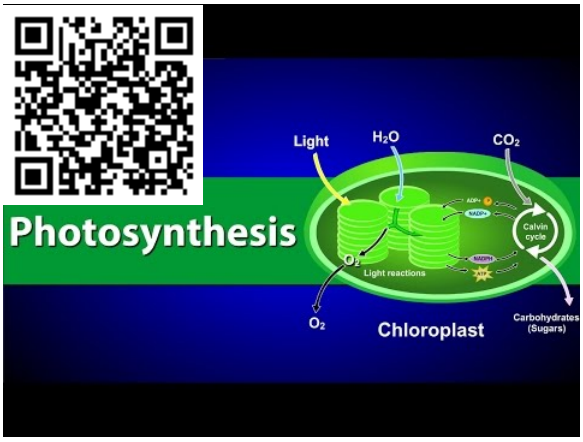
Although the equation looks simple, the many steps that take place during photosynthesis are actually quite complex. In plants, photosynthesis takes place primarily in the chloroplasts of leaves. Chloroplasts have a double (inner and outer) membrane. Within the chloroplast is a third membrane that forms 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 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 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.
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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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:

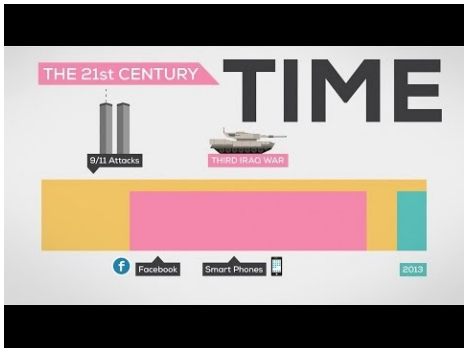


Figure 3.S.1. A video that provides some perspective about time, history, life, the universe, and everything.

Attributions

- CK12. (2014). *Biology*. Retrieved from http://www.ck12.org/user%3AZ3JlZ29yLmRpZXRlcmxlQGhvcml6b25jbGMub3Jn/book/CK-12-Biology/r1/. Available under Creative Commons Attribution-NonCommercial 3.0 Unported License. (CC BY-NC 3.0). Modified from Original.
- CK12. (2014). *Photosynthesis*. Retrieved from http://www.ck12.org/section/Photosynthesis-%3A%3Aof%3A%3A-MS-Cell-Functions-%3A%3Aof%3A%3A-CK-12-Life-Science-For-Middle-School/. Available under Creative Commons Attribution-NonCommercial 3.0 Unported License. (CC BY-NC 3.0). Modified from Original.
- OpenStax College. (2013). *Concepts of biology*. Retrieved from http://cnx.org/contents/b3c1e1d2-839...9a8aafbdd@8.10. OpenStax CNX. Available under Creative Commons Attribution License License 3.0 (CC BY 3.0). Modified from Original.
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CHAPTER OVERVIEW

4: Ecosystems 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



4.1: Energy Flow through Ecosystems
4.2: Biogeochemical Cycles
4.3: Terrestrial Biomes
4.4: Aquatic Biomes
4.5: Chapter Resources

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4.1: Energy Flow through Ecosystems



Figure 4.1.1. 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 4.1.1).

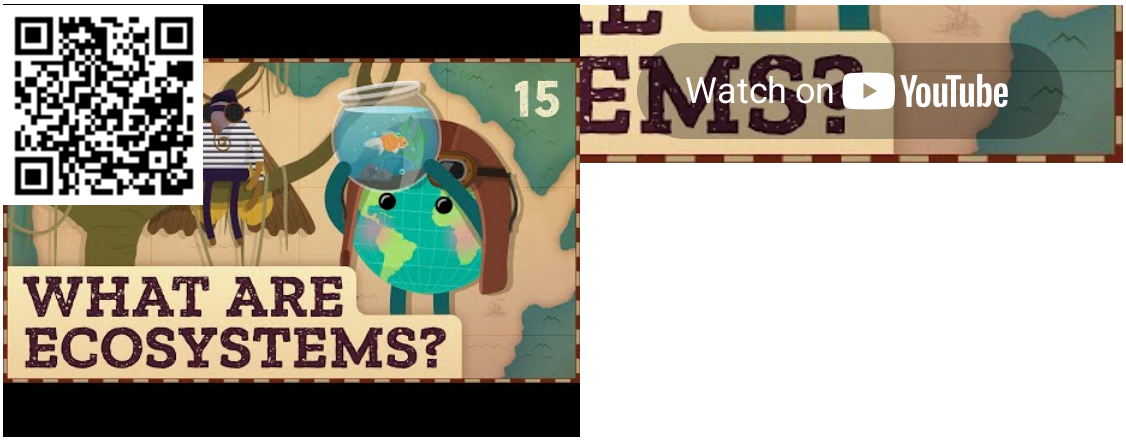
There are three broad categories of ecosystems based on their general environment: freshwater, marine, and terrestrial. Within these three categories are individual ecosystem types based on the environmental habitat and organisms present.

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 4.1.2).




15
WHAT ARE ECOSYSTEMS?
Watch on YouTube

Food Webs


Energy Flow within an Ecosystem
Isabella Coletta
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Figure 4.1.2. 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)

You may be familiar with **food chains** from prior learning experiences (Figure 4.1.3). However, food chains are not an accurate way of representing how natural feeding relationships actually work.

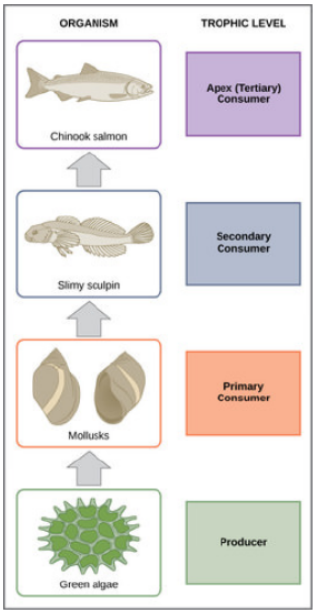


Figure 4.1.3. These are the trophic levels of a food chain in Lake Ontario at the United States–Canada border. Energy and nutrients flow from photosynthetic green algae at the base to the top of the food chain: the Chinook salmon. (credit: modification of work by National Oceanic and Atmospheric Administration/NOAA)

Instead, energy flow through ecosystems are best represented by **food webs**, a concept that accounts for the multiple trophic (feeding) interactions between each species (Figure 4.1.4 below). 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. A food web is a holistic model—which includes all the interactions between different species and their complex interconnected relationships with each other and with the environment—and is a more accurate and descriptive model for ecosystems.

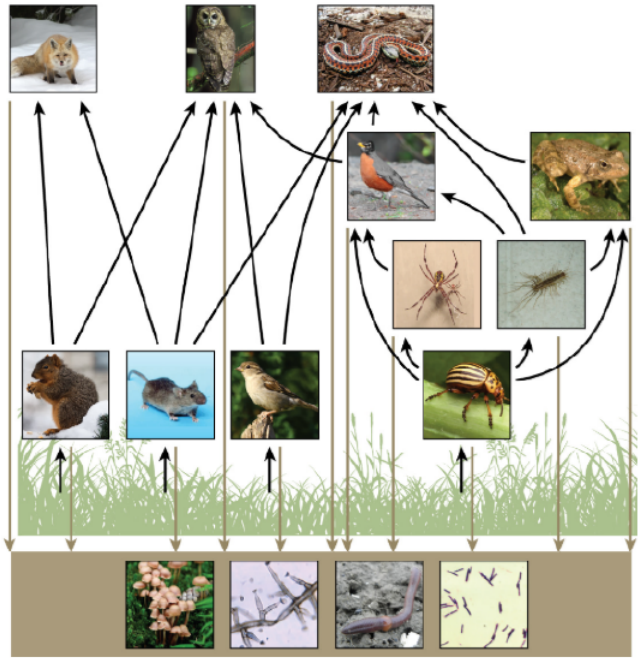


Figure 4.1.4. This food web shows the interactions between organisms across trophic levels. Arrows point from an organism that is consumed to the organism that consumes it. All the producers and consumers eventually become nourishment for the decomposers (fungi, mold, earthworms, and bacteria in the 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)

The levels in the food web are producers, primary consumers, higher-level consumers, and finally decomposers. These levels are used to describe ecosystem structure and dynamics. Each organism in a food web occupies a specific trophic level (energy level) at a given moment in time, depending on what it is eating.

In many ecosystems, the base, or foundation, of the food web consists of photosynthetic organisms (plants or phytoplankton), which are called **producers**. In other systems, the producers may be chemoautotrophs if there is no sunlight available, as at the bottom of the ocean or in caves. The organisms that consume the producers are 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 web.

One major factor that limits the number of steps in a food web is energy. Energy is lost at each trophic level and between trophic levels as heat and in the transfer to decomposers (Figure 4.1.5 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.

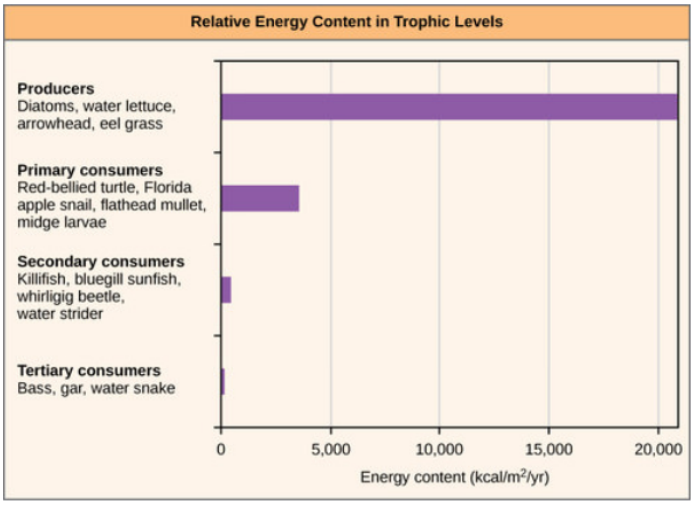
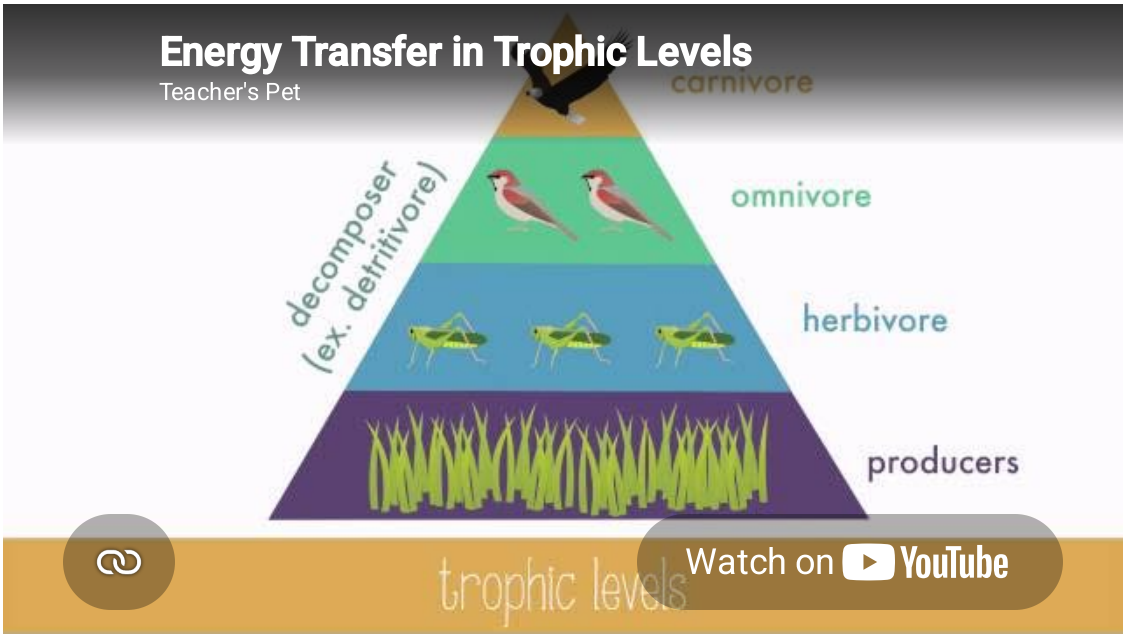
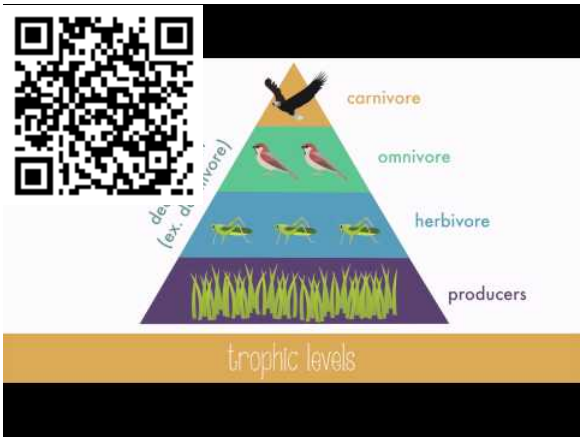


Figure 4.1.5. The relative energy in trophic levels in a Silver Springs, Florida, ecosystem is shown. Each trophic level has less energy available, and usually, but not always, supports a smaller mass of organisms at the next level.

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.

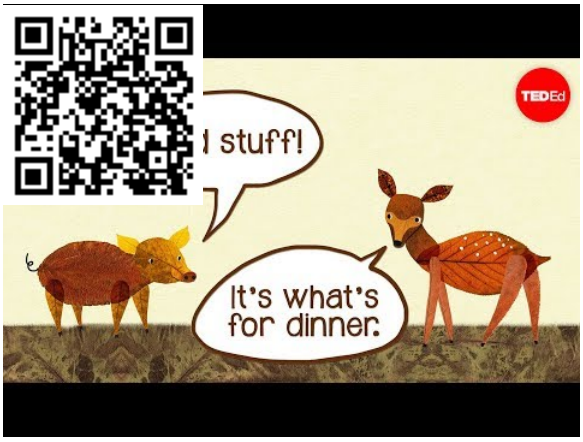



carnivore
omnivore
herbivore
producers
trophic levels

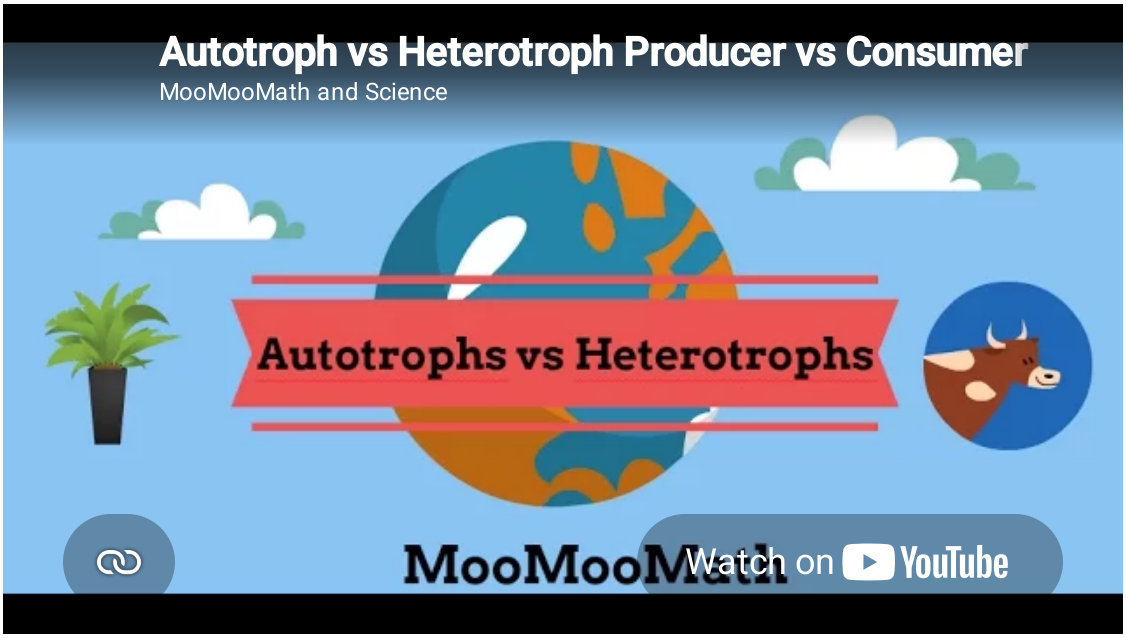

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How Organisms Acquire Energy in a Food Web





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.

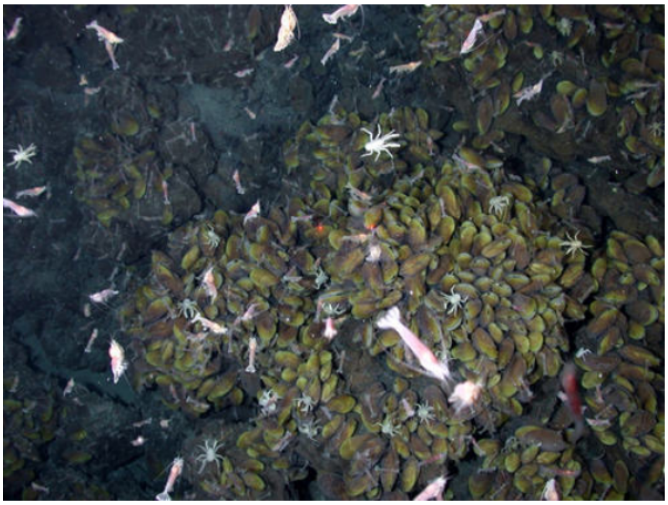


Figure 4.1.6. Swimming shrimp, a few squat lobsters, and hundreds of vent mussels are seen at a hydrothermal vent at the bottom of the ocean. As no sunlight penetrates to this depth, the ecosystem is supported by chemoautotrophic bacteria and organic material that sinks from the ocean's surface. This 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 4.1.6). 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.

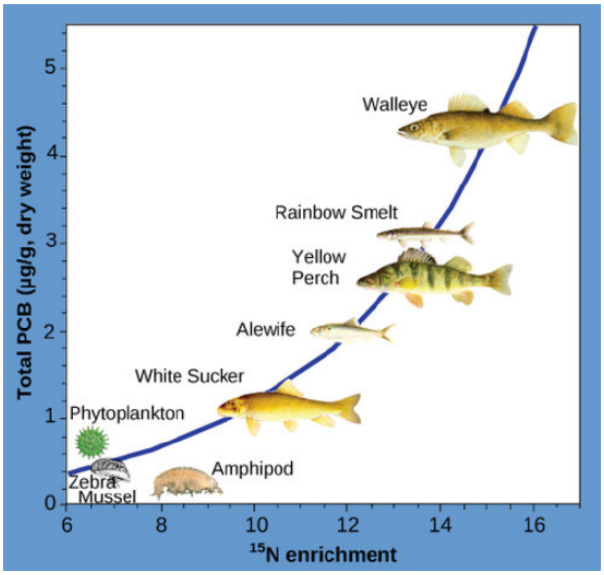
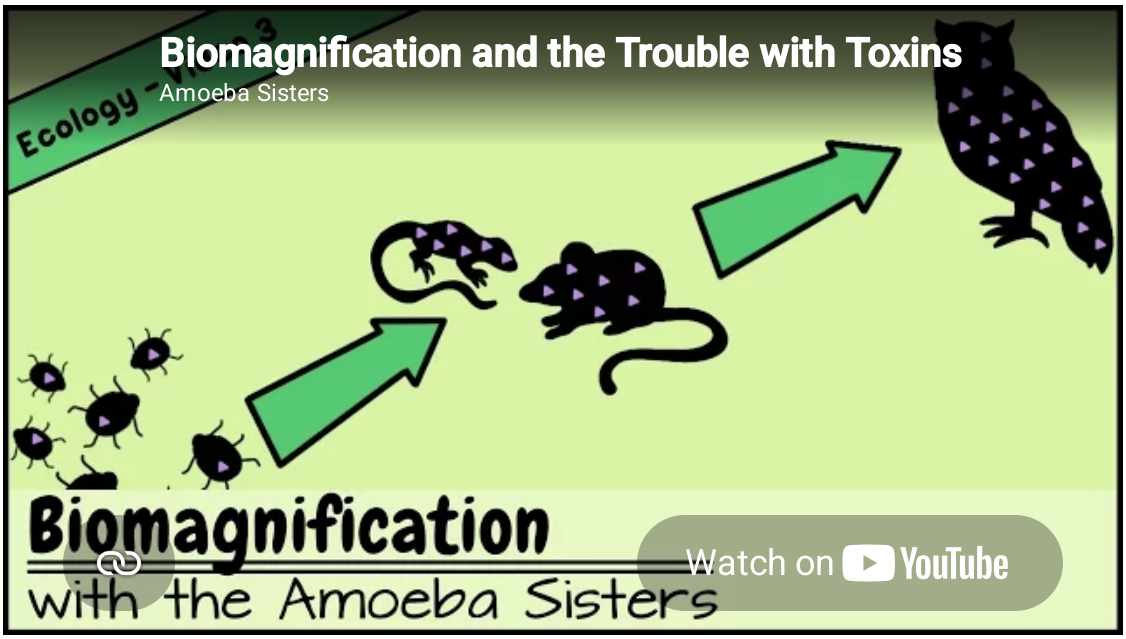


Figure 4.1.7. This chart shows the PCB concentrations found at the various trophic levels in the Saginaw Bay ecosystem of Lake Huron. Notice that the fish in the higher trophic levels accumulate more PCBs than those in lower trophic levels. (credit: Patricia Van Hoof, NOAA)

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 4.1.7 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 Materials

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

We're sorry, but there was an error playing this video. Please try again later.

Academy Award-winning Passion Pictures and HHMI Tangled Bank Studios present one of the most important but untold science stories of our time—a tale with profound implications for the fate of life on our planet. Beginning in the 1960s, a small band of young scientists headed out into the wilderness, driven by an insatiable curiosity about how nature works. Immersed in some of the most remote and spectacular places on Earth—from the majestic Serengeti to the Amazon jungle; from the Arctic Ocean to Pacific tide pools—they discovered a single set of rules that govern all life. Now in the twilight of their eminent careers, these five unsung heroes of modern ecology share the stories of their adventures, reveal how their pioneering work flipped our view of nature on its head, and give us a chance to reimagine the world as it could and should be.

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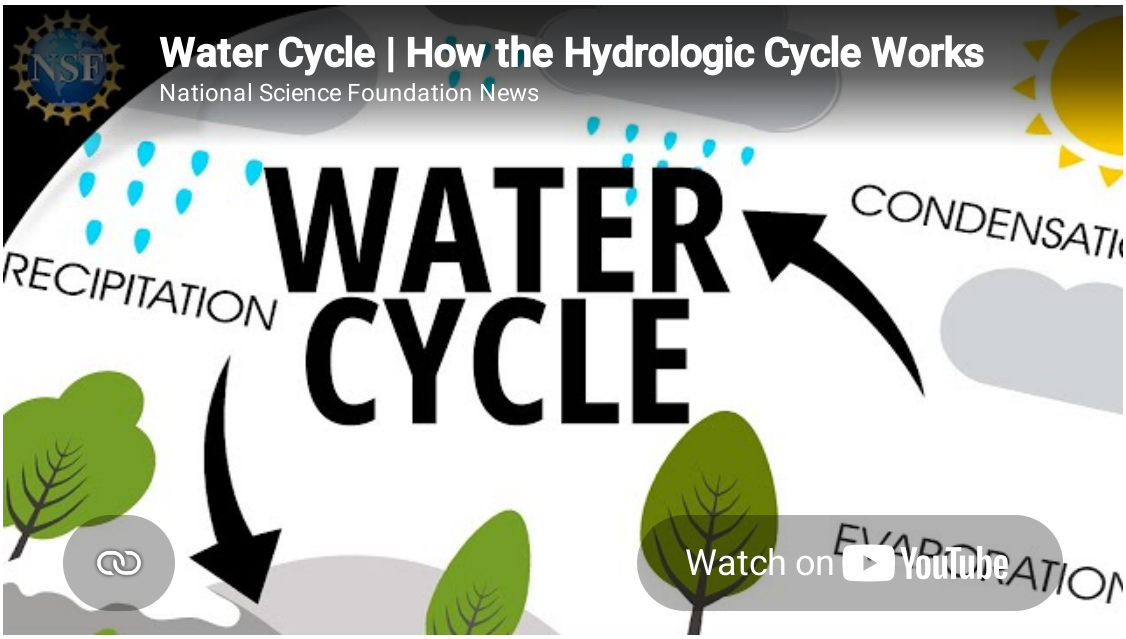
4.2: Biogeochemical Cycles

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 4.2.1 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 4.2.2 below. The processes include the following:

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

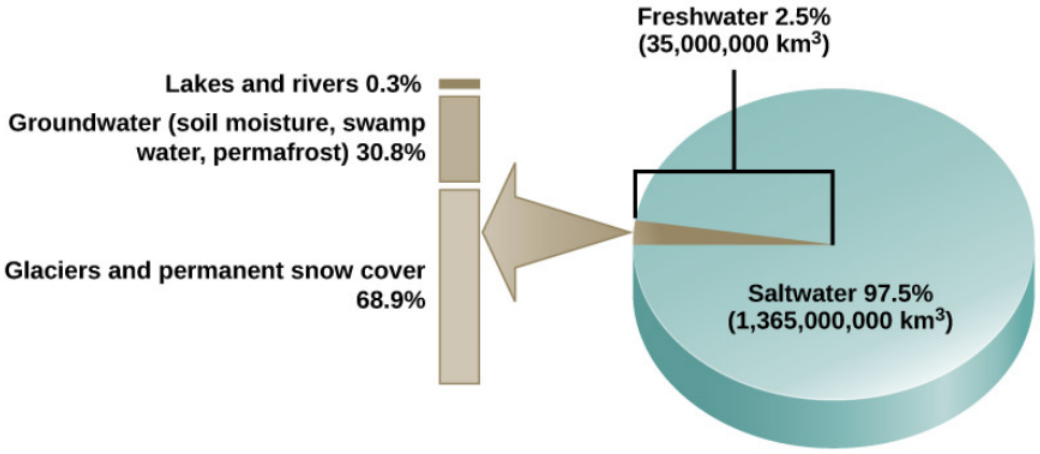


Figure 4.2.1. Only 2.5 percent of water on Earth is fresh water, and less than 1 percent of fresh water is easily accessible to living things.

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.

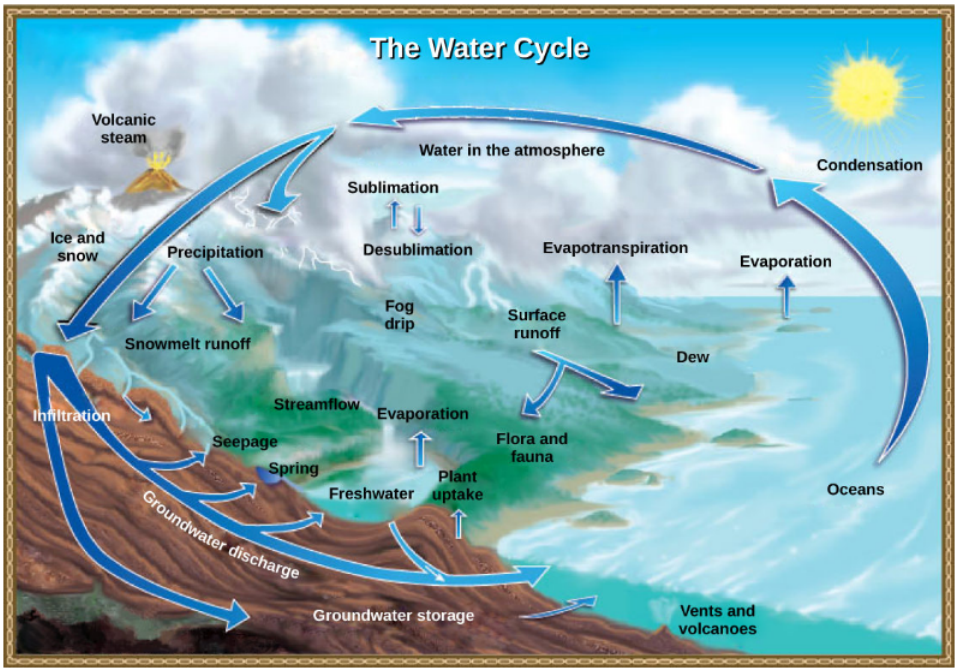


Figure 4.2.2. Water from the land and oceans enters the atmosphere by evaporation or sublimation, where it condenses into clouds and falls as rain or snow. Precipitated water may enter freshwater bodies or infiltrate the soil. The cycle is complete when surface or groundwater reenters the ocean. (credit: modification of work by John M. Evans and Howard Perlman, USGS)





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 4.2.3 below.

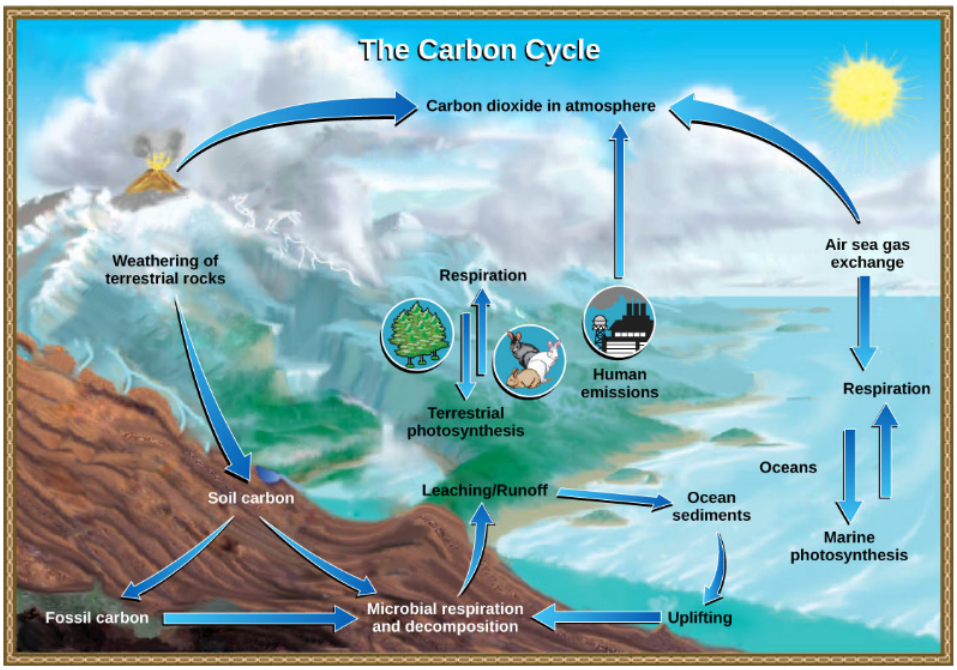


Figure 4.2.3. Carbon dioxide gas exists in the atmosphere and is dissolved in water. Photosynthesis converts carbon dioxide gas to organic carbon, and respiration cycles the organic carbon back into carbon dioxide gas. Long-term storage of organic carbon occurs when matter from living organisms is buried 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

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 4.2.4 below, the nitrogen that enters living systems is eventually converted from organic nitrogen back into nitrogen gas by bacteria (Figure 4.2.4). The process of **denitrification** is when bacteria convert the nitrates into nitrogen gas, thus allowing it to re-enter the atmosphere.

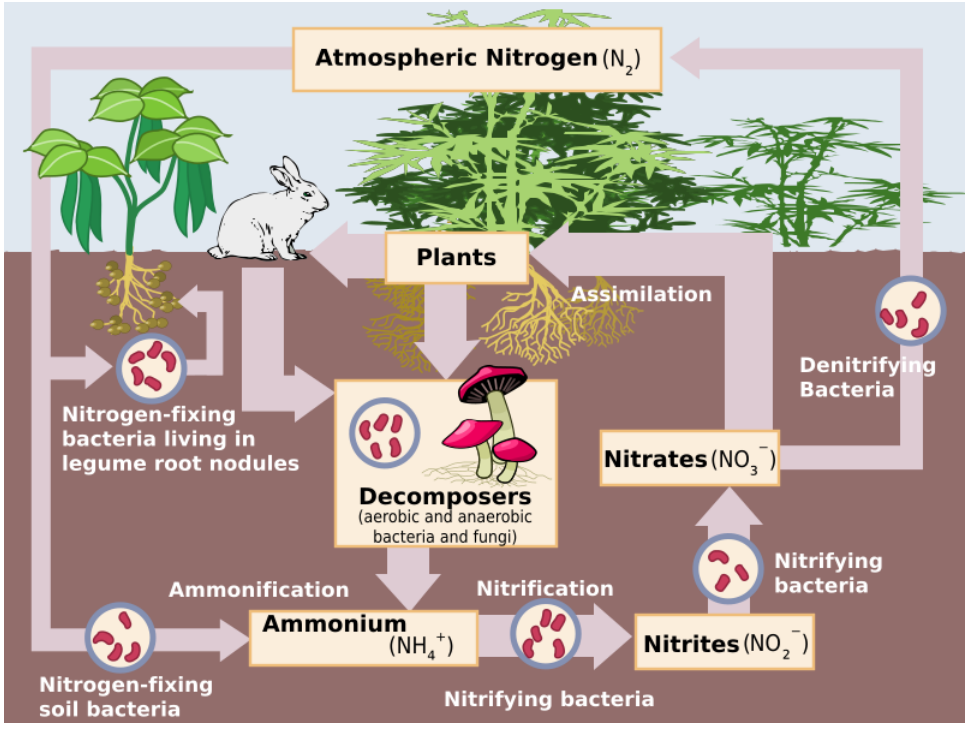


Figure 4.2.4. Nitrogen enters the living world from the atmosphere via nitrogen-fixing bacteria. This nitrogen and nitrogenous waste from animals is then processed back into gaseous nitrogen by soil bacteria, which also supply terrestrial food webs with the organic nitrogen they need. (credit: *"Nitrogen 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 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.

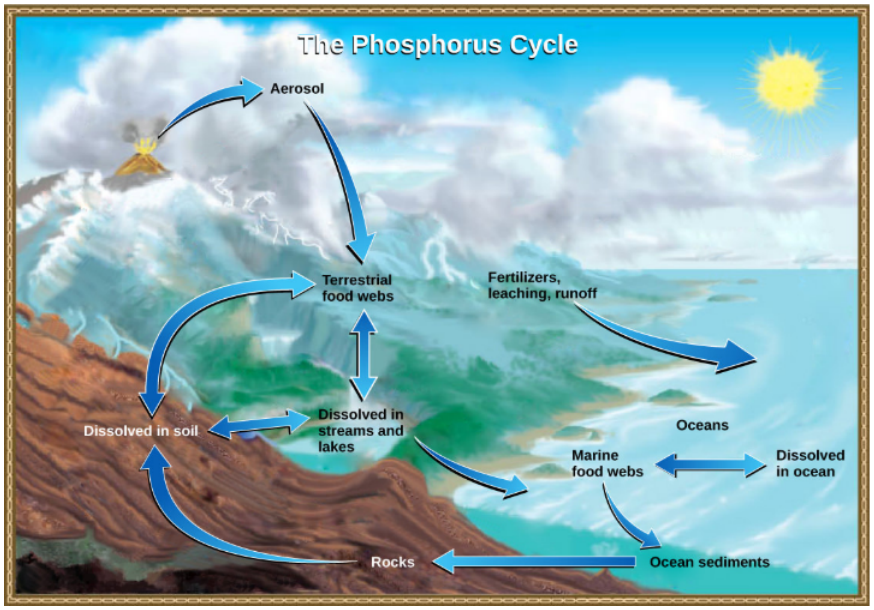


Figure 4.2.5. In nature, phosphorus exists as the phosphate ion (PO43-). Weathering of rocks and volcanic activity releases phosphate into the soil, water, and air, where it becomes available to terrestrial food webs. Phosphate enters the oceans in surface runoff, groundwater flow, and river flow. Phosphate 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 4.2.6 below).

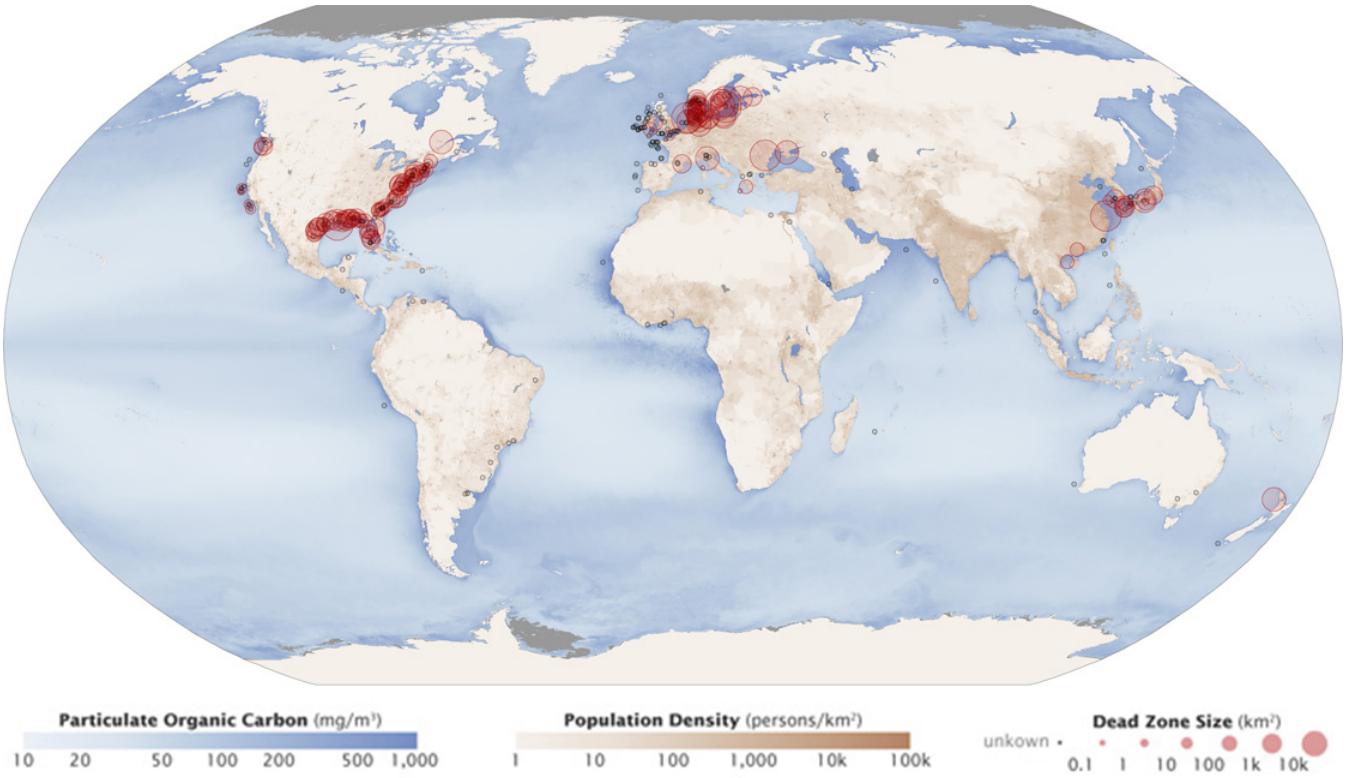
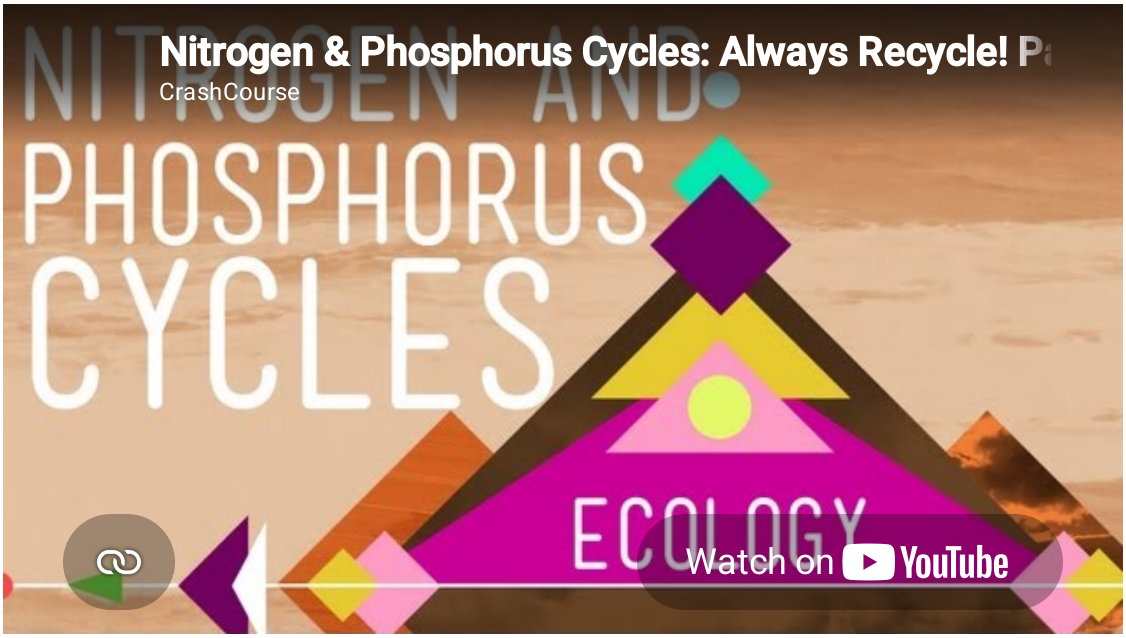


Figure 4.2.6. Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. Worldwide, large dead zones are found in coastal areas of high population density. (credit: NASA Earth Observatory)

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 4.2.7 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.

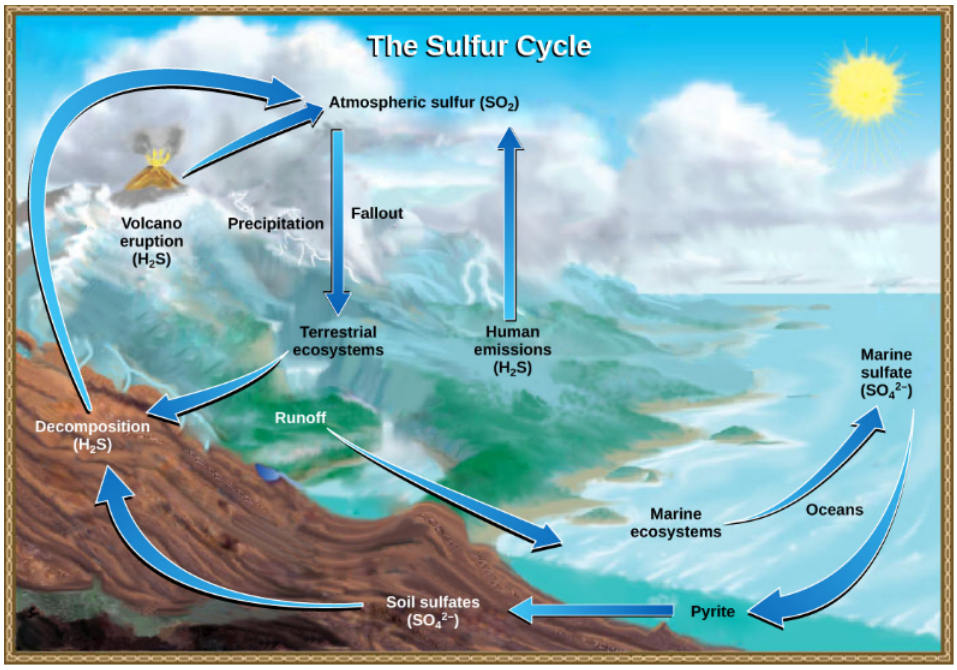


Figure 4.2.7. Sulfur dioxide from the atmosphere becomes available to terrestrial and marine ecosystems when it is dissolved in precipitation as weak sulfuric acid or when it falls directly to Earth as fallout. Weathering of rocks also makes sulfates available to terrestrial ecosystems. Decomposition 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>

Contributors and Attributions

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4.3: Terrestrial Biomes

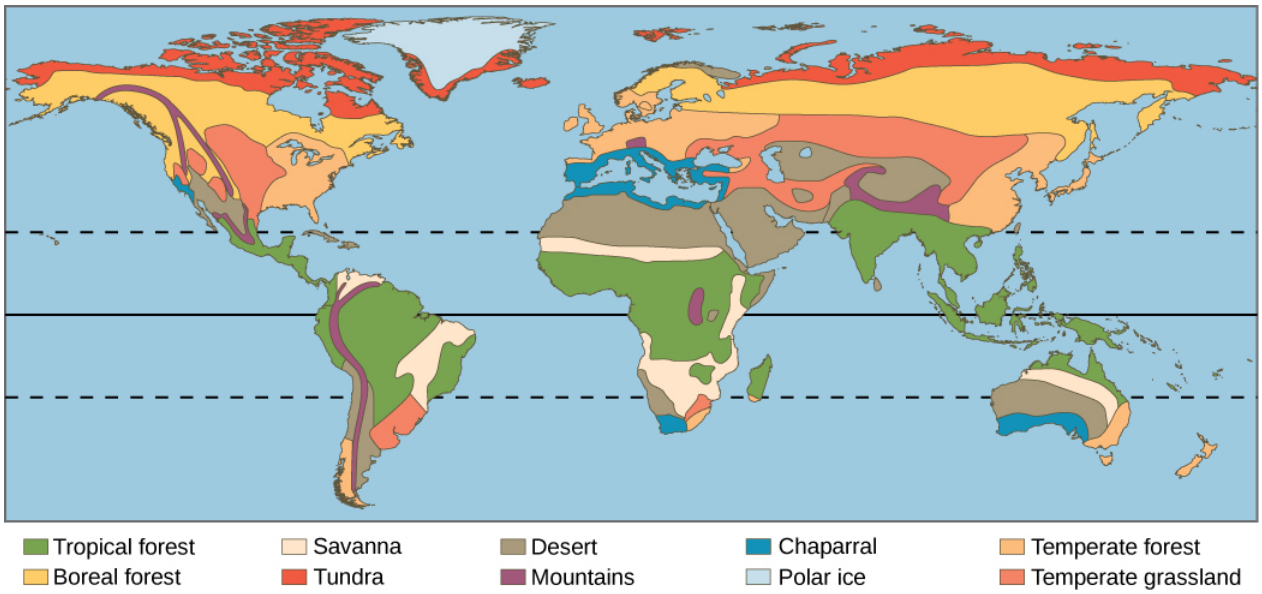


Figure 4.3.1***.*** *Each of the world's eight major biomes is distinguished by characteristic temperatures and amount of precipitation. Polar ice caps and mountains are also shown.*

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).

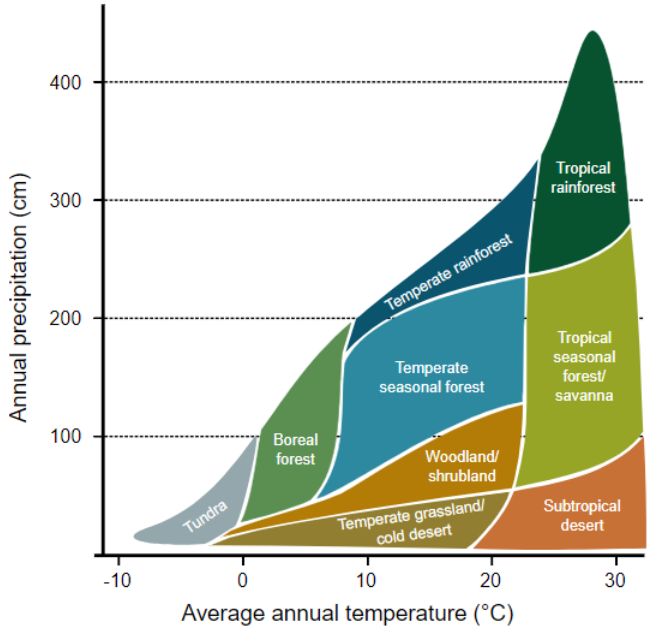
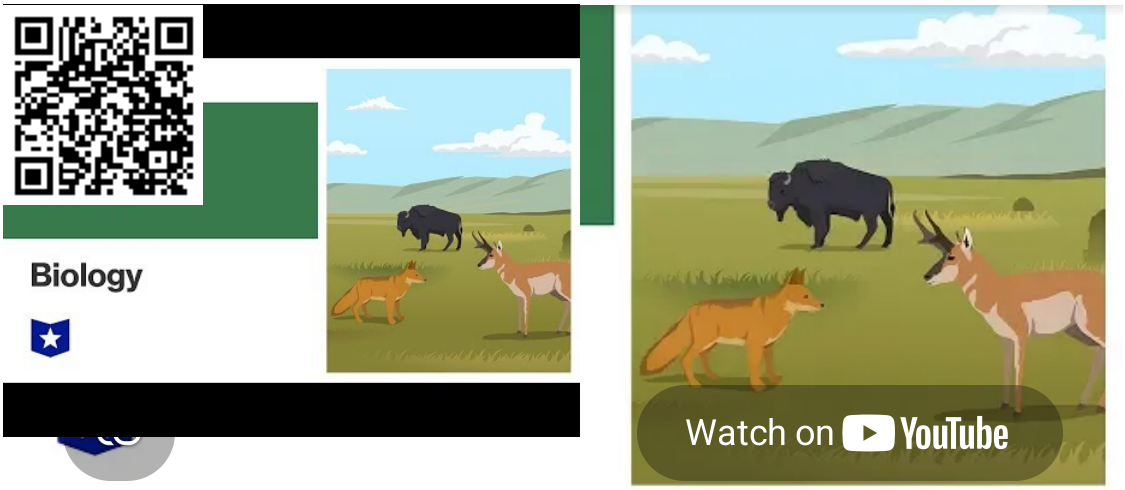


Figure 4.3.2. Precipitation and temperature are the two most important climatic variables that determine the type of biome in a particular location. Credit: "Climate influence on terrestrial biome" by Navarras is in the Public Domain, CC0





Deserts

Subtropical Deserts

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 4.3.6 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 4.3.6**.** *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 4.3.6 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.



Figure 4.3.7. 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)

Cold Deserts

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.

Chaparral

The **chaparral** is also called scrub forest and is found in California, along the Mediterranean Sea, and along the southern coast of Australia (Figure 4.3.7 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.



Figure 4.3.8. The chaparral is dominated by shrubs. (credit: Miguel Vieira)

Grasslands

Temperate Grasslands

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 4.3.8 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.



Figure 4.3.9. 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.

Savannas



Figure 4.3.5. 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)

Forests

Tropical rainforests

Tropical rainforests are found in equatorial regions (Figure 4.3.1) 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 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 leach nutrients from the soils of these forests.



Figure 4.3.3. 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 4.3.4***.*** *A MinuteEarth video about how trees create rainfall, and vice versa.*

Temperate Forests

Temperate forests are the most common biome in eastern North America, Western Europe, Eastern Asia, Chile, and New Zealand (Figure 4.3.9 below). This biome is found throughout mid-latitude regions. Temperatures range between –30ºC and 30ºC (–22ºF to 86ºF) 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.



Figure 4.3.10. Deciduous trees are the dominant plant in the temperate forest. (credit: Oliver Herold)

Boreal Forest

The **boreal forest,** also known as **taiga** or **coniferous forest**, is found roughly between 50°and 60° north latitude across most of Canada, Alaska, Russia, and northern Europe (Figure 4.3.10 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.



Figure 4.3.11. 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.

Tundra

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 4.3.12. 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 4.3.11 below). There is little species diversity, low net primary productivity, and low above-ground biomass. The soils 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>

Contributors and Attributions

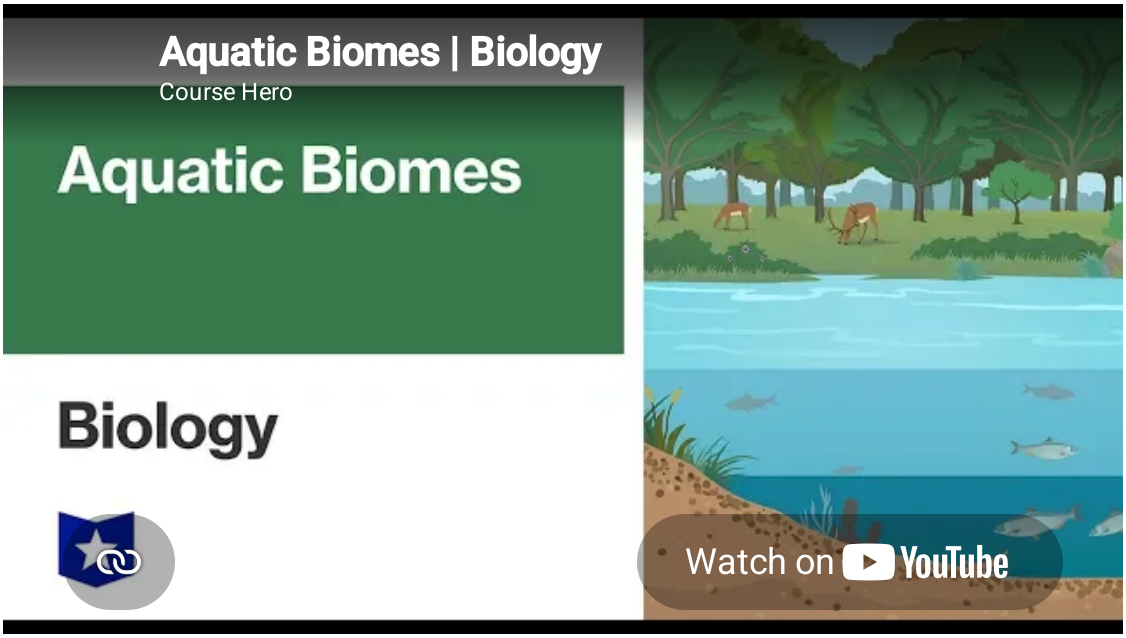
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4.4: Aquatic Biomes

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.

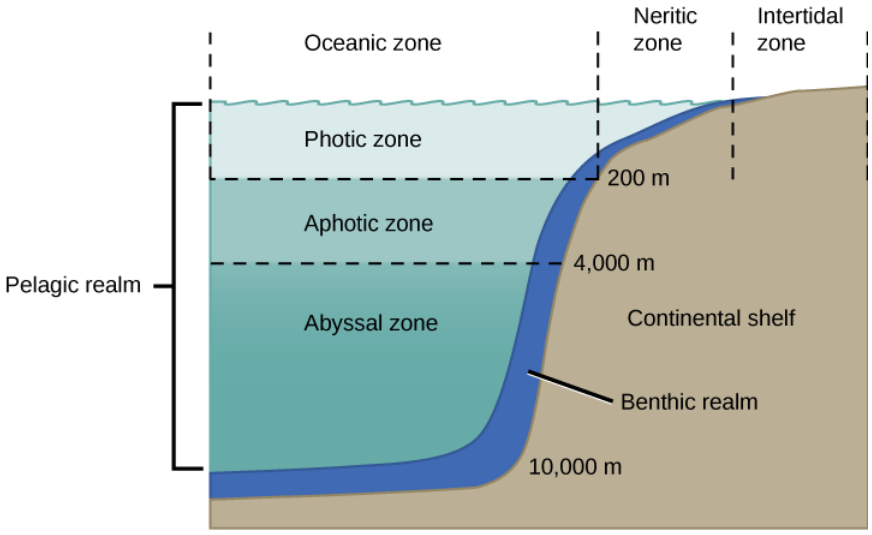


Figure 4.4.1. The ocean is divided into different zones based on water depth and distance from the shoreline.

The ocean is categorized by several areas or zones (Figure 4.4.1). 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 4.4.2). 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 4.4.2). 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 4.4.2. 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 4.4.1) 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 4.4.1). 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 4.4.1) 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 4.4.1), 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 4.4.3).



Figure 4.4.3. 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 4.4.4. 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 4.4.4) 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 4.4.5. 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)

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 4.4.5).

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4.5: 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. Human Populations and Resources

Click here to view this infographic on current population growth before beginning (How do population clocks work?)

Population projection to 2100:



5.1: History and Global Distribution
5.2: Carrying Capacity
5.3: Population Growth

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5.1: History and Global Distribution

Introduction

As noted in the previous unit, a population refers to a group of individuals living together in a specific area at a particular time. Changes in populations are referred to as **population dynamics**. Population dynamics includes the reasons populations grow and decline (births, deaths, immigration, and emigration) as well as the reasons why populations live in different areas (**spatial distribution**).

The human population, therefore, is made up of all of the people who currently live on Earth. Since the first humans (*Homo sapiens sapiens*) evolved millions of years ago, our population and distribution have constantly changed. While humans are unique in many ways, we are subject to many of the same forces that control population growth and decline, including unexpected events, as all other organisms.

How Many Humans Are There?

- In 1999, the human population rose to six billion individuals.
- In 2010, the human population reached seven billion individuals.
- In 2022, 8 billion people were recorded.
- At current growth rates, the population will double within 50 years.

Long ago, when the number of humans was small (Figure 5.1.1), the doubling of the population had little impact on individuals and the environment.

However, with today's population in the billions, the effect of doubling the population is quite significant. Already, most of the people of the world do not have adequate clean water, food, housing, and medical care, and these deficiencies are at least partially the result of overpopulation. The good news is that the overall growth rate of humans has slowed. On the other hand, because of inertia, the overall human population will continue to grow for some time.

It is important to note that it is not so much the total number of humans that matters. As the population continues to grow, competition for resources increases. This is especially true as developed nations and individuals in them consume more **per capita** (per individual), and developing/underdeveloped countries strive to reach the quality of life of developed nations.

For example, we grow more food on Earth than can be eaten by the world's population. However, food is not distributed equally; social and political factors play much more of a part in the impact of human consumption than the sheer number of individuals. Natural disasters and political conflicts will exacerbate the problems, especially in the more stressed regions of developing and underdeveloped nations. The survivors of this competition will likely be determined by factors such as place of birth and educational opportunities.

Video



In this 10-minute video, the following ideas are covered. Is the world overpopulated or underpopulated? While we worry about there being too many people for the planet to support, we can also worry about how fewer people in a given place may affect the economy, what may happen when there are more elderly people who need care than there are healthcare workers, or even be concerned about how many people are necessary to carry on other aspects of culture.

Question after watching: Which ideas follow from the previous unit and which are new to studying human populations?

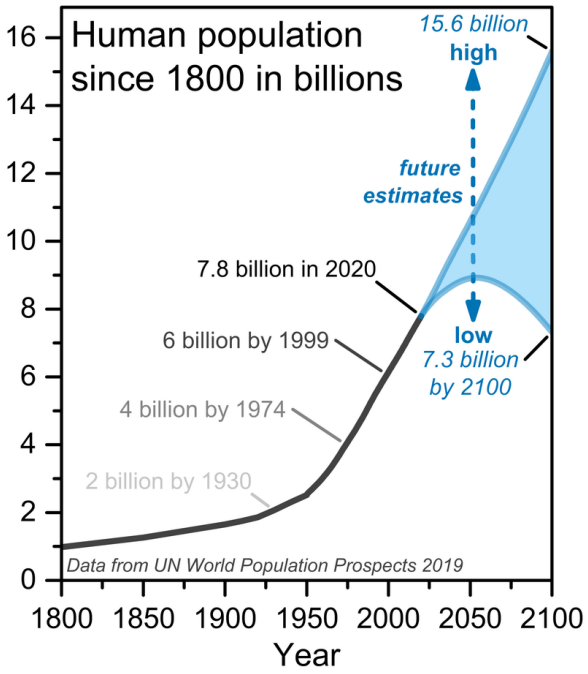


Figure 5.1.1: Human world population since 1800 with projections of future population. (Copyright Bdm25 via Wikipedia under CC BY-SA 4.0)

Population Growth

Human populations are not stagnant. They naturally change in size, density and predominance of age groups in response to environmental factors such as resources availability and disease, as well as social and cultural factors. The increases and decreases in human population size make up what is known as **human population dynamics**. If resources are not limited, then populations experience exponential growth. A plot of **exponential growth** over time resembles a "J" curve. Absolute numbers are relatively small at first along the base of the **J curve**, but the population rapidly skyrockets when the critical time near the stem of the J curve is reached.

For most of the history of modern humans (Homo sapiens), people were hunter-gatherers. Food, especially meat from large mammals, was usually plentiful. However, populations were small because the nomadic life did not favor large family sizes. During those times, the human population was probably not more than a few million worldwide. It was still in the base of the J growth curve.

Video



It's tough to know what happened on Earth thousands of years before anyone started writing anything down. But thanks to the amazing work of anthropologists and paleontologists like those working on National Geographic's Genographic Project, we can begin to piece together the story of our ancestors as this 2.5 minute video explains. Question after watching: How did humans populate the globe from East Africa?

Video

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Access to this content has been restricted. Contact your internet service provider for help.

Watch the human population grow from 1 CE to the present and see projected growth in under six minutes. One dot = 1 million people.

Video



From about 2 million years ago until 13,000 years ago there were several human species inhabiting the earth. In fact, 100,000 years ago there were at least 6 different human species! Today there's only us: Homo sapiens. In this 5-minute video, we're going to look at some of the key moments in our population growth, and what the future might look like.

With the end of the last Ice Age, roughly 10,000 years ago, the climates worldwide changed and many large mammals that had been the mainstay of human diet became extinct. This forced a change in diet and lifestyle, from one of the nomadic hunter-gatherer to that of a more stationary agricultural society.

Humans began cultivating food and started eating more plants and less meat. Having larger families was possible with the more stationary lifestyle. In fact, having a large family increasingly became an asset, as extra hands were needed for maintaining crops and homes. As agriculture became the mainstay of human life, the population increased.

As the population increased, people began living in villages, then in towns, and finally in cities. This led to problems associated with overcrowded conditions, such as the buildup of wastes, poverty, and disease. Large families were no longer advantageous. Infanticide was common during medieval times in Europe, and communicable diseases also limited the human population numbers. Easily spread in crowded, rat-infested urban areas, Black Death, the first major outbreak of the Bubonic Plague (1347-1351) drastically reduced the populations in Europe and Asia, possibly by as much as 50 percent.

Starting in the 17th Century, advances in science, medicine, agriculture, and industry allowed rapid growth of human population and infanticide again became a common practice.

The next big influence on the human population occurred with the start of the Industrial Revolution in the late 18th century. With the advent of factories, children became valuable labor resources, thereby contributing to survival, and family sizes increased. The resulting population boom was further aided by improvements in agricultural technology that led to increased food production. Medical advancements increased control over disease and lengthened the average lifespan. By the early 19th century, the human population worldwide reached one billion. It was now in the stem of the J-curve graph. As the world approached the 20th century, the human population was growing at an exponential rate.

Video



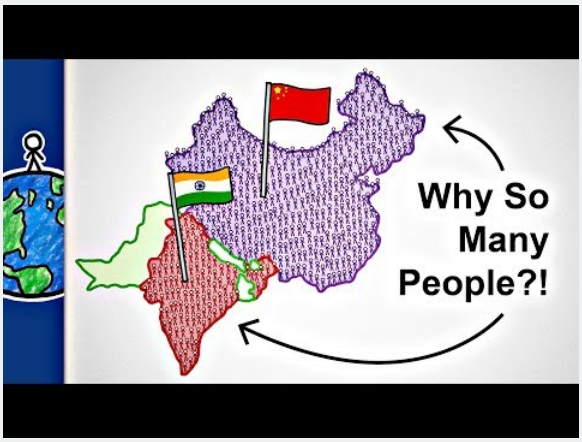


U.N. forecasts suggest the world population could hit a peak of 10.1 billion by 2100 before beginning to decline. But exact numbers are hard to come by — just small variations in fertility rates could mean a population of 15 billion by the end of the century. In this 2.5-minute video, learn more.

Question after watching: What factors increased growth the most over the last 200 years?

Video



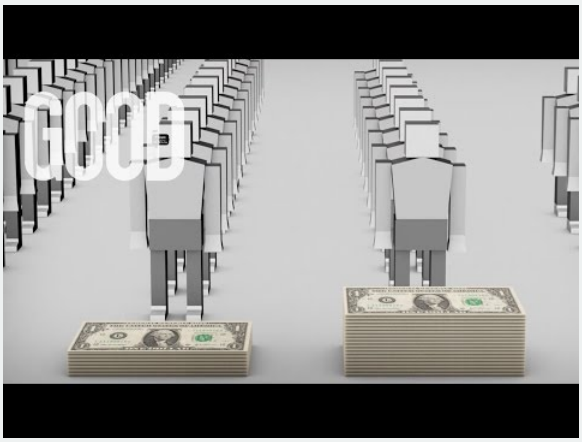


In this 3-minute video, learn why India and China have so many people today.
Question after watching: What are the factors that have given India and China a head-start on population growth?

During the 20th century, another important event in human population dynamics occurred. The birth rates in highly developed countries decreased dramatically. Factors contributing to this decrease included: a rise in the standard of living, the availability of practical birth control methods, and the establishment of child education and labor laws. These factors made large families economically impractical. In Japan, the birth rate has been so low in recent years that the government and corporations are worried about future labor shortages. Therefore, they are actively encouraging population growth. In contrast, the populations in less well-developed countries continue to soar. Worldwide, the human population currently exceeds eight billion and continues to grow exponentially. How much more the world population will grow is a topic of intense speculation. One thing is certain: exponential growth cannot continue forever, as Earth's resources are limited.

Video

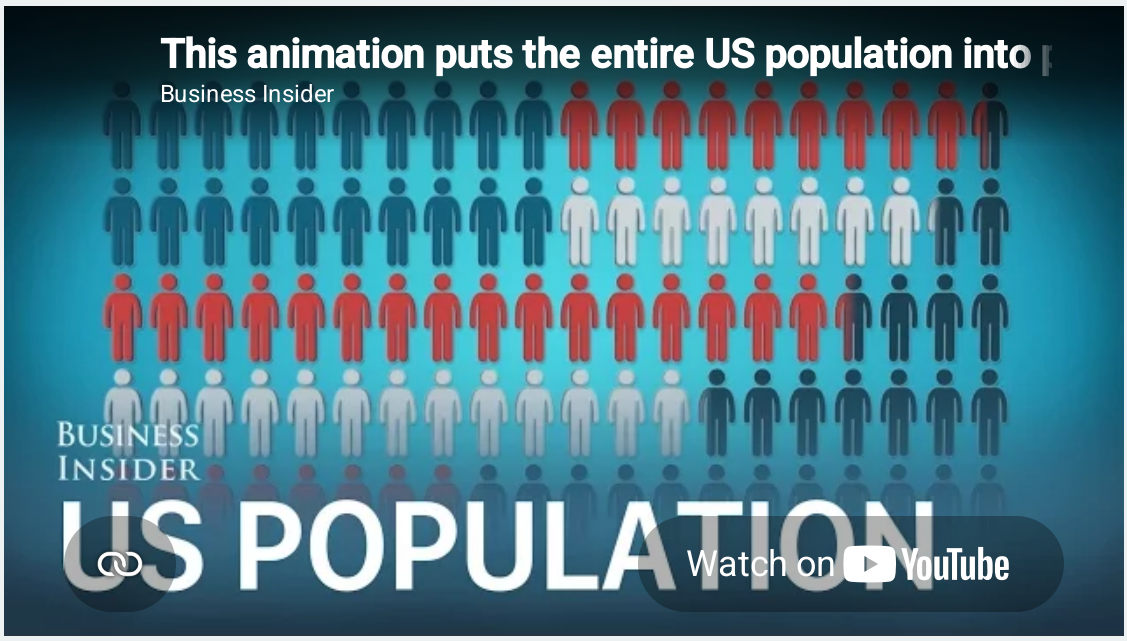


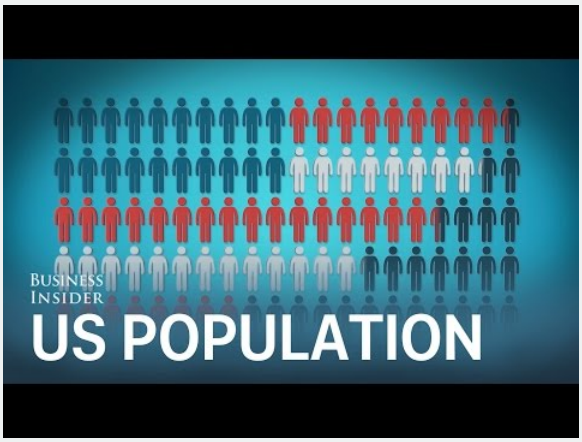


If the population of the world was only 100 people, what would society look like? Find the answers in this short 2.5-minute animation.

Question after watching: What new information did you learn that you did not know about the global population before?

Note





What does the population of the US look like? It might help to shrink it down a bit. This 2.5-minute animation illustrates how the US would break down if it were a village of just 100 people.
Question after watching: Contrast this with the previous video. What are similarities and differences in the US versus global population?

Population Demographics

Human **demography** (population change) is usually described in terms of the births and deaths per 1000 people. When births of an area exceed deaths, population increases. When the births of an area are fewer than deaths, the population decreases. The annual rate at which the size of a population changes is:

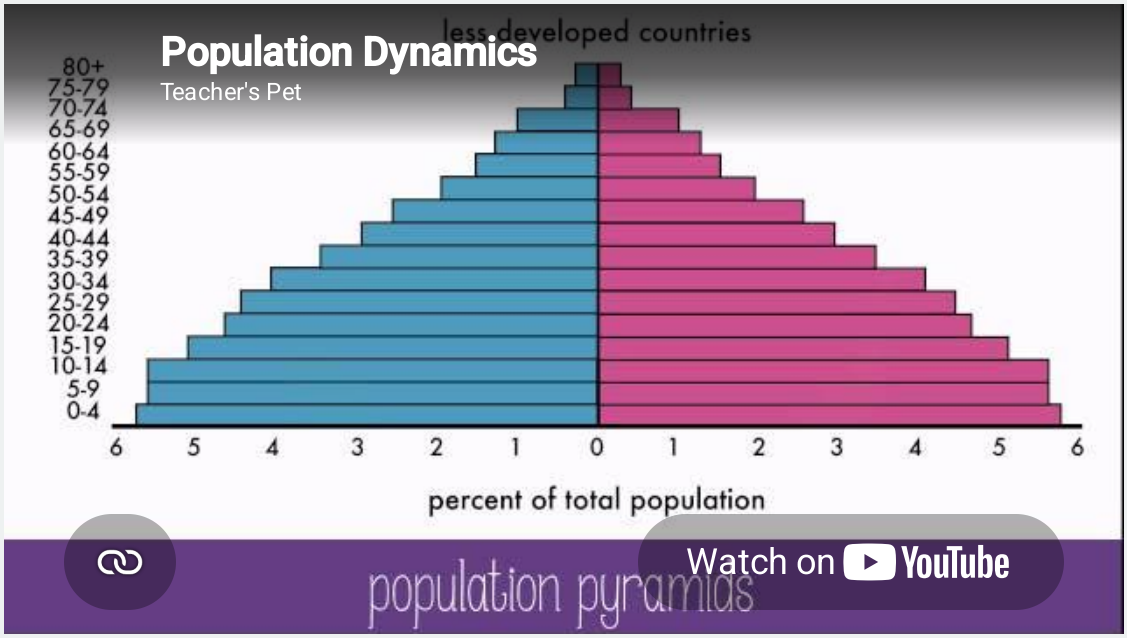
$$\text{Natural Population Change Rate } \% = \frac{(\text{Births - Deaths})}{1000} \times 100 \tag{5.1.1}$$

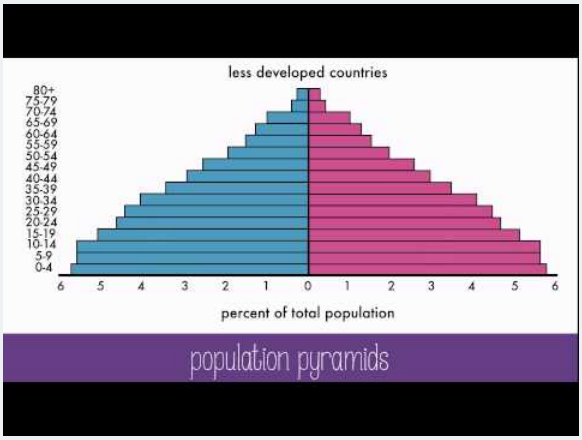
During the year 2000, the birth rate for the world was 22 and the death rate was 9. Thus, the world's population grew at a rate of 1.3 percent. The annual rate of population change for a particular city or region is also affected by **immigration** (movement of people into a region) and **emigration** (movement out of a region).

$$\text{Population Change Rate} = \left(\begin{array}{c}\text{Birth}\\ \text{rate}\end{array} + \begin{array}{c}\text{Immigration}\\ \text{Change Rate}\end{array}\right) - \left(\begin{array}{c}\text{Death}\\ \text{rate}\end{array} + \begin{array}{c}\text{Emigration}\\ \text{rate}\end{array}\right) \quad (5.1.2)$$

Highly industrialized nations, like the United States, Canada, Japan and Germany, generally have low birth and death rates. Annual rates of natural population change vary from -0.1% to 0.5%. In some industrial nations (e.g. Germany and Russia) death rates exceed birth rates so the net population decreases over time. Newly industrialized countries (e.g. South Korea, Mexico and China) have moderate birth rates and low death rates. The low death rates result from better sanitation, better heath care and stable food production that accompany industrialization. The annual rates of natural population change are about 1 percent to 2 percent in these countries. Countries with limited industrial development (e.g. Pakistan and Ethiopia) tend to have high birth rates and moderate to low death rates. These nations are growing rapidly with annual rates of natural population change exceeding 2 percent.

Video





Learn how to calculate growth rate, interpret growth diagrams, survivorship curves, population pyramids (age structures), exponential and logistic growth in this 4.5-minute video!

Several factors influence **human fertility**. Important factors influencing birth and fertility rates in human populations are: affluence, average marriage age, availability of birth control, family labor needs, cultural beliefs, religious beliefs and the cost of

raising and educating children.

The rapid growth of the world's population over the past 100 years mainly results from a decline in death rates. Reasons for the drop in death rates include better nutrition, fewer infant deaths, increased average life span, and improvements in medical technology.

As countries become developed and industrialized, they experience a movement from high population growth to low population growth. Both death and birth rates decline.

These countries usually move from rapid population growth, to slow growth, to zero growth, and finally to a reduction in population. This shift in growth rate with development is called the "**demographic transition**." Four distinct stages occur during the transition: pre-industrial, transitional, industrial, and post-industrial.

1. During the **pre-industrial stage**, harsh living conditions result in a high birth rate and a high death rate. The population grows very slowly, if at all.
2. The **transitional stage** begins shortly after industrialization. During this phase, the death rate drops because of increased food production and better sanitation and health conditions, but, the birth rate remains high. Therefore, the population grows rapidly.
3. During the **industrial stage**, industrialization is well established in the country. The birth rate drops and eventually approaches the death rate. Couples in cities realize that children are expensive to raise and that having large families restrict their job opportunities.
4. The **post-industrial** stage occurs when the birth rate declines even further to equal the death rate, thus population growth reaches zero. The birth rate may eventually fall below the death rate, resulting in negative population growth.

The United States and most European countries have experienced this gradual transition over the past 150 years. The transition moves much faster for today's developing countries. This is because improvements in preventive health and medical care in recent decades have dramatically reduced mortality -- especially infant mortality -- and increased life expectancy. In a growing number of countries, couples are having fewer children than the two they need to "replace" themselves. However, even if the level of "**replacement fertility**" were reached today, populations would continue to grow for several decades because of the large numbers of people now entering their reproductive years.

As a result of reduced fertility and mortality, there will be a gradual demographic shift in all countries over the next few decades toward an older population. In developed countries, the proportion of people over age 65 has increased from 8% to 14% since 1950 and is expected to reach 25% by 2050. Within the next 35 years, those over age 65 will represent 30% or more of the population in Japan and Germany. In some countries, the number of residents over age 85 will more than double.

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5.2: Carrying Capacity

Introduction

The human carrying capacity is a concept explored by many people, most famously Thomas Robert Malthus (1766 - 1834), for hundreds of years. **Carrying capacity, "K,"** refers to the number of individuals of a population that can be sustained indefinitely by a given area. At carrying capacity, the population will have an impact on the resources of the given area, but not to the point where the area can no longer sustain the population. Just as a population of wildebeest or algae has a carrying capacity, so does a human population.

Humans, while subject to the same ecological constraints as any other species (a need for nutrients, water, etc.), have some features as individuals and some as a population that make them a unique species. Unlike most other organisms, humans have the capacity to alter their number of offspring, level of resource consumption and distribution. While most women around the world could potentially have the same number of children during their lives, the number they actually have is affected by many factors. Depending upon technological, cultural, economic and educational factors, people around the world have families of different sizes. Additionally, unlike other organisms, humans invent and alter technology, which allows them to change their environment. This ability makes it difficult to determine the human K.

Figure 1: Exponential Growth of Population Size Over Time

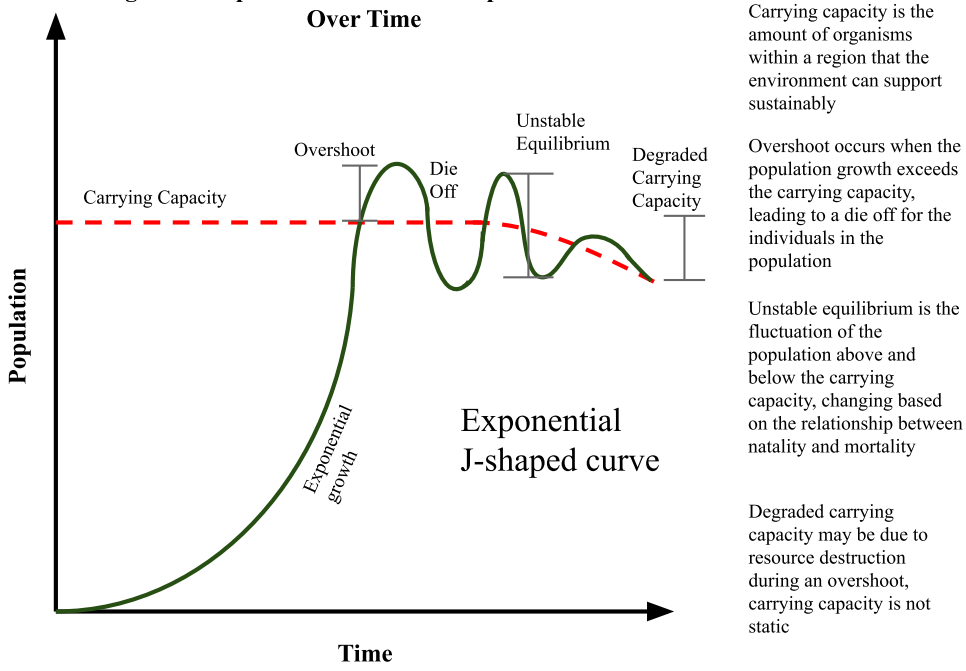


Figure 5.2.1: Reaching carrying capacity through exponential growth, followed by die of and carrying capacity degredation (Copyright; Nchisick CC BY-SA 4.0)

Patterns of Resource Use

Humans have always made an impact on the environment through their use of resources. Early humans were primarily hunter-gatherers who used tools to survive. They fashioned wood and stone tools for hunting and food preparation, and used fire for cooking. Early humans developed methods for changing habitat to suit their needs and herding wild animals. As time passed, humans developed more tools and techniques and came to rely on that technology in their daily lives. Although the tools of early humans were primitive by today's standards, they significantly affected the environment and probably hastened the extinction of some large Ice Age mammals.

After the end of the last Ice Age, some eight to 10,000 years ago, humans began domesticating wild animals and plants. The first known instance of farming started in a region extending from southeastern Turkey to western Iran, known as the **fertile crescent**.

These early farmers domesticated crops such as chickpea, bitter vetch, grapes, olives, barley, emmer wheat, lentils, and flax. They hybridized wheat for making bread from wild grass and emmer wheat. They also domesticated animals such as sheep, goats, cattle and pigs. The fertile crescent's unique diversity of wild crops and animals offered humans a mix of basic agricultural commodities that allowed a revolution in the development of human society. With a reliable food supply, humans were able to stay in one place and be assured of having a constant supply of carbohydrates, protein, milk and oil. They had animals for transportation and plant and animal materials for producing clothing and rope. Agricultural economies soon displaced hunter-gatherer economies. Within 2,000 years, farming ranged from Pakistan to southern Italy.

Most early agriculture was subsistence farming in which farmers grew only enough food to feed their families. Agriculture underwent another important revolution about 5,000 years ago with the invention of the plow. The plow allowed humans to clear and farm larger plots of land than was otherwise possible. This increased the food supply and a concomitant increase in human population growth. More efficient farming methods also resulted in urbanization because a few farmers could produce a large surplus of food to feed those in the urban areas.

Over the last 10,000 years, land clearing for agriculture has destroyed and degraded the habitats of many species of plants and animals. Today, growing populations in less developed countries are rapidly clearing tropical forests and savannas for agricultural use. These tropical rainforests and savannas provide habitat for most of the earth's species. It has become clear that modern agricultural practices are not sustainable. Once-fertile areas are becoming infertile because of overgrazing, erosion and nutrient depletion. Furthermore, modern agriculture requires large inputs of energy and fertilizers, usually produced from nonrenewable fossil fuels.

The next major cultural change, the **Industrial Revolution**, began in England in the mid-18th century. It involved a shift from small-scale production of goods by hand to large-scale production of goods by machines. Industrial production of goods increased the consumption of natural resources such as minerals fuel, timber and water by cities. After World War I, more efficient mass production techniques were developed, and industrialization became prevalent in the economies of the United States, Canada, Japan and western Europe.

Advanced industrialization leads to many changes in human society, and some of those changes negatively affect the supply of natural resources and result in environmental degradation. These changes include: increased production and consumption of goods by humans, dependence on non-renewable resources such as oil and coal, production of synthetic materials (which may be toxic or non-biodegradable) and consumption of large amounts of energy at home and work.

Other changes may have positive benefits. These include: creation and mass production of useful and affordable products, significant increases in the average **Gross National Product** per person, large increases in agricultural productivity, sharp rises in average life expectancy and a gradual decline in population growth rates.

The information age was born with the invention of miniaturized electronics such as integrated circuits and computer central processing units. This stage in human development has changed and continues to change society as we know it. Information and communication have become the most-valued resources. This shift in turn, may lessen our influence on the earth's environment through reduced natural resource consumption. For instance, in recent years energy use in the United States has not increased to the extent expected from economic growth. Online shopping, telecommuting and other Internet activities may be lessening human energy consumption.

By making good use of information technologies, less developed countries may be able to reduce potential environmental problems as their economies expand in the future. With so much information easily available, developing countries may not repeat the environmental mistakes that more developed countries made as they became industrialized.

Note

This website contains a great visualization of the material wealth of representative families from around the world: https://www.pbs.org/wgbh/nova/worldbalance/material.html

Effects of Technology and the Environment

When scholars in the 1700's estimated the total number of people that today earth could sustain, they were living in a very different world than our world. Today airplanes can transport people and food half way around the world in a matter of hours, not weeks or months, as was the case with ships in the 1700s. Today we have sophisticated, powered farm equipment that can rapidly plow, plant, fertilize and harvest acres of crops a day. One farmer can cultivate hundreds of acres of land. This is a far cry from the draft-animal plowing, hand planting and hand harvesting performed by farmers in the 1700s. Additionally, synthetic fertilizers, pesticides and modern irrigation methods allow us to produce crops on formerly marginal lands and increase the productivity of other agricultural lands. With the increase in the amount of land that each individual can farm, the food production has increased. This increased food production, in turn, has increased the potential human K relative to estimates from the 1700s.

Whereas technological advances have increased the human K, changes in environmental conditions could potentially decrease it. For example, a global or even a large regional change in the climate could reduce K below current estimates. Coastal flooding due to rising ocean levels associated with global warming and desertification of agricultural lands resulting from poor farming practices or natural climate variation could cause food production to be less than that upon which the human carrying capacity was originally estimated.

There are those who believe that advances in technology and other knowledge will continue to provide the means to feed virtually any human population size. Those who subscribe to this philosophy believe that this continuous innovation will "save us" from ourselves and changes in the environment.

Others believe that technology will itself reach a limit to its capabilities. This group argues that resources on earth -- including physical space – are limited and that eventually we must learn to live within our means. Aside from the physical limitations of the earth's natural resources and food production capabilities, we must consider the conditions we are willing to live with.

Video



Effect of Standard of Living

Given the wherewithal to do so, humans have aesthetic expectations in their daily lives. This is a consideration that is less evident in other species. While the earth might be able to hold many more than the current human population of six billion (estimates of the human K with current technology go as high as 50 billion) at some point people will find it unacceptable to live with the crowding and pollution issues associated with a dramatic increase in population. The qualitative measure of a person's or population's quality of life is called its **standard of living**. It is associated not only with aesthetics of surroundings and levels of noise, air and water pollution, but also with levels of resource consumption.

Americans have one of the world's highest standards of living. While there are many who live in poverty in the United States, on average we have relatively small families, large homes, many possessions, plentiful food supplies, clean water and good medical care. This is not the case in most of the developing world.

While many nations have larger average family sizes, they have smaller homes, fewer possessions and less food. Supplies of clean water may be scarce and medical care may be inadequate. All people desire to have adequate resources to provide good care for

their families, and thus population in most developing countries are striving for standard of living of developed nations.

Is it possible for all six billion people on earth to live at the same level of resource use as in the United States, Japan and Western Europe? With current technology, the answer is "no." However, this does not mean that the people of one nation are more or less entitled to a given standard of living than those of another. What it does mean for citizens of nations like the United States is that we must reduce our current use of resources. Of all of the food purchased by the average American family, 10 percent is wasted. In addition, because most Americans are not vegetarians, we tend to eat high on the food chain, which requires more resources than a vegetarian diet.

Calculation of ecological efficiency indicate that from one trophic level on the food chain to the next, there is only a 10 percent efficiency in the transfer of energy. Thus people who predominately eat more grains, fruits and vegetables are getting more out of the energy required to produce the food than those who eat a lot of meat. The calories that a person gets from beef are much fewer than the calories in the grain required to raise the cattle. The person is better off skipping the middleman -- or middle cow in this case -- and eating the grain. This is why many more people can be sustained on a diet that consists of a larger percentage of rice, millet or wheat, rather than of fish, beef or chicken.

In addition to resources used to provide food, Americans use disproportionate amounts of natural resources such as trees (for paper, furniture and building, among other things) and fossil fuels (for automobiles, homes and industry). We also produce a great amount of "quick waste." Packaging that comes on food in the grocery store is a good example of quick waste. The hard plastic packaging used for snack foods that is immediately removed and thrown away and plastic grocery bags are both examples of quick waste. Thus, patronizing fast food restaurants increases resource consumption and solid waste production at the same time.

Note





In this 5.5-minute video, discover how the impacts that humans have made have become so pervasive, profound, and permanent that some geologists believe we merit our own epoch.

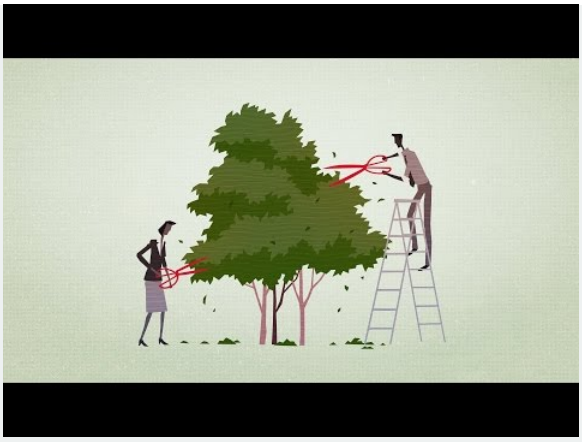
Question after watching: Describe several ways we are dependent on the organisms on Earth for our very survival.

The good news for the environment (from both a solid waste and a resource use standpoint) is that we can easily reduce the amount of goods and resources that we use and waste without drastically affecting our standard of living. By properly inflating car tires, America could save millions of barrels of oil annually. If we were to use more renewable energy resources -- like solar and wind power as opposed to petroleum and nuclear energy --there would be a reduced need to extract non-renewable resources from the earth. The amount of packaging used for goods could also be reduced. Reusable canvas bags could be used for shopping and plastic and paper grocery bags could be reused.

At home, many waste materials could be recycled, instead of being thrown away. These relatively easy steps could reduce the overall ecological impact that each person has on the earth. This impact is sometimes termed a person's **ecological footprint**. The smaller each person's ecological footprint, the greater the standard of living possible for each person. More on this will be discussed throughout this text.

Video





Learn about the Sustainable Economic Development Assessment, or SEDA, in this 2.5-minute video. Question after watching: How can this assessment be used to better understand the quality of life in countries around the world?

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5.3: Population Growth

Introduction

Families in developing nations are often larger, but less resource-intensive (e.g., they use fewer resources per person) than those in more developed nations. However, increasingly human populations wish to have a "western" standard of living. An increase in the world's average standard of living significantly lowers the potential human carrying capacity of the earth. Therefore, in order to reduce their impact as a species, humans must not only reduce the resources they use per person, they must also reduce their average family size.

Determining ways to reduce family size requires an understanding of the many factors determining family size and the resultant population dynamics of the region.

Many economic and cultural influences affect family size. Depending upon the prevailing cultural values and economic forces, a nation's people can be induced to have larger or smaller families.

Although human population dynamics are often considered on a global scale, factors that affect population growth vary in different parts of the world. Therefore, it is essential to understand the different forces acting on people throughout the world.

Video



Hank is here to tell us in 10-minutes the specifics of why and how human population growth has happened over the past hundred and fifty years or so, and how those specifics relate to ecology.
Question after watching: Why have humans been so successful?

Economic Factors

Some of the factors influencing family size -- and therefore population growth -- are economic ones. These factors are probably the most easily understood. For instance, a rural agricultural family in a developing country that relies upon a plow pulled by a water buffalo needs many family members to take care of the planting, harvesting and marketing of crops. A family of three would not provide enough labor to sustain the family business.

In contrast, families in developed countries tend to be small for economic reasons. It is expensive to raise children at the relatively high standard of living found in such countries. Considerable resources must be devoted to food, clothes, transportation, entertainment and schooling. A large proportion of children from developed countries attend college, thus adding even more to the expense. Therefore, it is economically prudent in such countries for families to have few children.

Obviously, there are technological and educational ways to negate the need for many children. If the farm family in a developing country is able to obtain better farming tools and information, they can improve the farm's production by irrigating crops and by using techniques such as crop rotation (e.g., planting different crops in different years to maintain soil fertility, prevent erosion and maximize yields). With the acquisition of such new tools and farming techniques, fewer family members are required to work the same amount of land. The land may even become more productive, even with less manual labor.

Additional economic factors -- such as the cost of medical care and retirement care -- also play a role in family size. If a family is unable to afford adequate medical care, then family planning services and birth control materials may not be attainable. Also, when mortality rates for children are high and significant numbers of children do not live to adulthood, there is a strong motivation to have as many children as possible.

Doing so ensures that some of the children will live to help in the family business, and provide a link to posterity.

Without national social security programs like those in the United States and Sweden, the elderly in developing countries rely on younger, working members of their families to support them in their retirement. A larger family means a more secure future. The expense of a national social security program also acts to reduce family size in a country, as the high taxes imposed on workers to support the system makes supporting large families difficult.

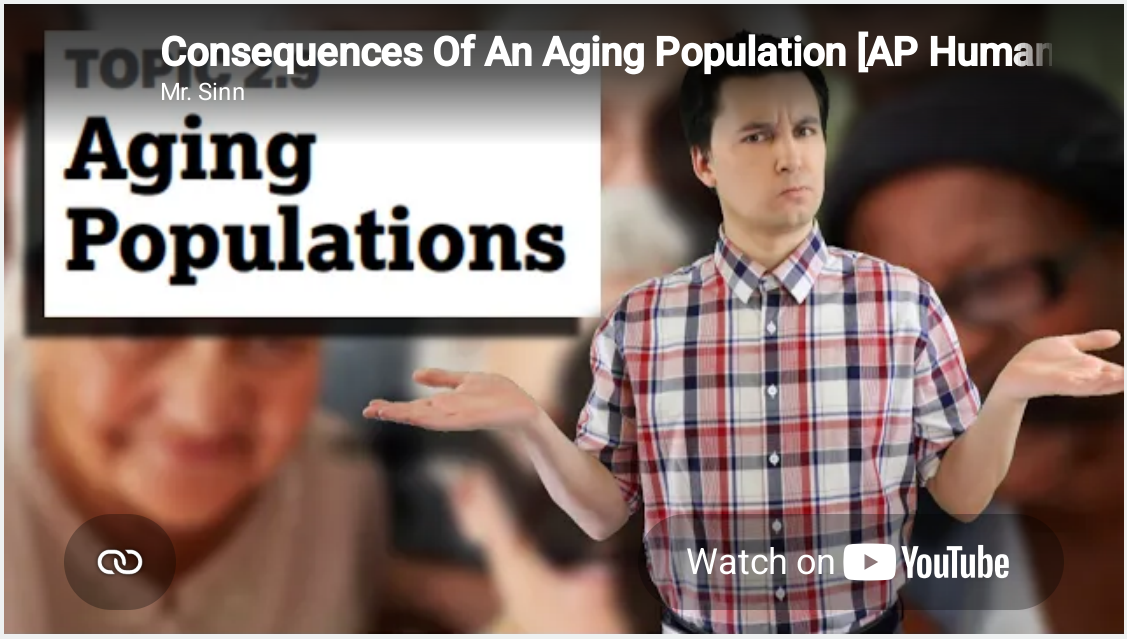
Video





This 4-minute video explains the intent and effects of various population and immigration policies on population size and composition. [Note: China no longer has their one-child policy in place]
Question after watching: What are some types of population policies profiled in the video?

Video





In this 5-minute video, discover the causes and consequences of an aging population.
Question after watching: What are the political, social, and economic consequences of a shrinking population?

Cultural Factors

Around the globe, **cultural factors** influence family size and as a result, affect population growth rate. From a cultural standpoint, religion can have a profound effect on family planning. Many religions promote large families as a way to further the religion or to glorify a higher power. For example, Orthodox Judaism encourages large families in order to perpetuate Judaism. Roman Catholicism promotes large families for the same reason, and forbids the use of any "artificial" means of birth control. Devout followers of a religion with such values often have large families even in the face of other factors, such as economic ones. This can be seen in countries like Israel (Judaism) and Brazil (Catholicism), which have high percentages of religious followers in their populations. Both countries have high birth rates and high population growth rates.

Various factors involving women can also affect family sizes. These factors include: education and employment opportunities available to women, the marriage age of women and the societal acceptance of birth control methods. These factors are sometimes strongly influenced by society's cultural attitudes towards women.

Around the world, statistics indicate that with higher levels of education, women are more likely to be employed outside the home; in addition, higher marriage age of women and the greater the acceptance of birth control methods, the smaller the family size. It is

clear that increasing educational and professional opportunities for women would reduce overall population growth and improve standards of living worldwide.

Video



SDG4 aims to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". This 6-minute video describes many of the issues and solutions around SDG4.
Question after watching: What are some of the barriers and solutions to education around the world?

Video



SDG5 aims to "Achieve gender equality and empower all women and girls". This 10-minute video describes many of the issues and solutions around SDG5
Question after watching: Why is SDG5 an accelerator for other SDGs?

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CHAPTER OVERVIEW

6: Climate Change

Video



We've known about the greenhouse effect for nearly 200 years and about global warming for more than a century, but we've had a hard time acting because human brains aren't a good match for a problem this big.
Question after watching: What do you already know about the science of climate change? What are you ready to learn more about?

6.1: Introduction to Climate Change
6.2: Anthropogenic Climate Change
6.3: Current and Future Climate Change Impacts
6.4: Climate Strategies

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Introduction to Climate Change

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Define global climate change
- Summarize the effects of the Industrial Revolution on global atmospheric carbon dioxide concentration
- Describe three natural factors affecting long-term global climate
- List two or more greenhouse gases and describe their role in the greenhouse effect

Introduction

Remember from Unit 4 that all biomes are universally affected by global conditions, such as climate. These conditions ultimately shape each biome's environment. Scientists who study climate have noted a series of marked changes that have become increasingly evident over the last 70 years.

Climate change refers to the complete set of climate characteristics—temperature, precipitation, pressure systems, wind patterns, and oceanic currents—changing locally, regionally, and globally over time due to human influences.

It is closely related to **global warming**, also called global heating, which describes the general trend of increasing global temperatures we see under climate change. However, *climate change* includes all of the effects of a warming planet, not just rising global temperatures, and is a more appropriate term for what this Unit examines.

Climate and Weather

A common misconception about global climate change is that a specific weather event occurring in a particular region (for example, a very cool week in June in central Nebraska) is evidence of global climate change. However, a cold week in June in Nebraska is a *weather*-related event and not a *climate*-related one. If the trend in summer temperatures in Nebraska indicated cooling over time, that would mean it was a change in climate.

These misconceptions often arise because of confusion over the terms climate and weather.

Video



Discover the real reason we confuse weather and climate in this 5-minute video from Hot Mess (US PBS). Question after watching: How does our personal experience of weather have an effect on how we view climate change?

Climate refers to the long-term, predictable atmospheric conditions of a specific area. A biome's climate is characterized by consistent temperature and annual rainfall ranges. Climate does not address the amount of rain that fell on one particular day in a biome or the colder-than-average temperatures that occurred one season.

In contrast, **weather** refers to the conditions of the atmosphere during a short period of time. Weather forecasts are usually made for 48-hour cycles. Long-range weather forecasts are available but can be unreliable.

To better understand the difference between climate and weather, imagine that you are planning an outdoor event in Boston, MA. You would be thinking about *climate* when you plan the event in the summer rather than the winter because you have long-term knowledge that any Saturday in May through August would be a better choice for an outdoor event in Boston than a Saturday in January. However, you cannot determine the specific day on which that event should be held because it is difficult to accurately predict the *weather*. Climate can be considered “average” weather.

Global Climate Change

Climate change can be understood through three areas of study:

- current and past global climate change
- causes of past and present-day global climate change
- ancient and current results of climate change

When reading or viewing media about global climate change, it is helpful to clearly separate these three aspects of climate change.

Standard climate change reporting often confuses the data and suffers from a misguided approach of presenting "both sides" as equally valid. While balanced reporting is appropriate for political and economic topics, it is misleading in scientific contexts. Traditional media (cable news, newspapers, official news social media, etc.) frequently provide climate change skeptics a platform whose views do not align with scientific consensus. Social media influencers make this even worse.

Pseudoscience, misinformation, and/or disinformation practices create confusion and allow personal opinions to be valued and legitimized on the same level as the scientific consensus.

- Misinformation is false or inaccurate information—getting the facts wrong.
- Disinformation is false information that is deliberately intended to mislead, intentionally misstating the facts.

By presenting these unsubstantiated opinions alongside scientific research, these practices undermine the integrity of climate science.

As you learned in Unit 1, scientific theories are based on evidence, not opinion, and require rigorous peer review to be considered credible.

The Greenhouse Effect

When heat energy from the sun strikes the Earth, **greenhouse gases** (carbon dioxide, methane, water vapor, nitrous oxide, and chlorofluorocarbons (CFCs)) trap the heat in the atmosphere, just as the glass panes of a greenhouse keep heat from escaping.

Approximately half of the sun's radiation passes through these gases in the atmosphere and strikes the Earth. This radiation is converted into thermal (heat) radiation on the Earth’s surface, and a portion of the thermal energy is re-radiated back into the atmosphere.

Greenhouse gases, however, reflect much of the thermal energy back to the Earth’s surface. The more greenhouse gases in the atmosphere, the more thermal energy is reflected back to the Earth’s surface. Greenhouse gases absorb and emit radiation and are an important factor in the greenhouse effect, the warming of Earth due to carbon dioxide and other greenhouse gases in the atmosphere. Without the greenhouse effect, Earth would be a cold planet like Mars. However, too much of a greenhouse effect causes surface and ocean temperatures that many organisms are not adapted to.

Video



Discover the intricacies of Earth's greenhouse effect in this 3-minute video.
Question after watching: How do the so-called greenhouse gases act to insulate the Earth? Why do more greenhouse gases lead to a warmer planet?

Optional Activity 6.1.2

What is the greenhouse effect?

A. Certain gases in the atmosphere trap heat and warm the Earth
B. Life on Earth 'exhales' gas that warms up the atmosphere
C. The tilt of the Earth changes the amount of solar energy the Earth receives
D. The Sun is putting out more radiant energy over time

Answer

A. Certain gases in the atmosphere trap heat and warm the Earth.

Evidence for Past Global Climate Change

Since scientists cannot go back in time to directly measure climatic variables, such as average temperature and precipitation, they must instead indirectly measure temperature. To do this, scientists rely on historical evidence of Earth's past climate. Indirect evidence includes data from boreholes (a narrow shaft bored into the ground), tree rings, glacier lengths, pollen remains, and ocean sediments.

The primary sources of evidence, however, are ice cores. **Ice cores** are samples of ice from ice sheets or high mountain glaciers. In 2025, the deepest core was drilled yet: nearly 2 miles. The ice cores are like traveling backwards through time; the deeper the sample, the earlier the time period. This 2025 core is providing 1.2 million years of trapped bubbles of air and other biological evidence that can reveal temperature and carbon dioxide (CO_2) data.

The most famous ice core is the Vostok core from Antarctica that provided evidence from the last 400,000 years (Figure 6.1.1a). The 0°C on this graph refers to the long-term, modern-day average. Temperatures that are greater than 0°C exceed Earth's long-term average temperature. Conversely, temperatures that are less than 0°C are less than Earth's average temperature. This figure shows that there have been increasing and decreasing temperatures over approximately 100,000-year cycles.

When thinking about past climates, it is important to keep scales in mind.

Time:

In the distant past, the Earth was as much as 9°C/16°F cooler and as much as 3°C/5.4°F warmer, and most of the past 400,000 years have been colder than today. Most of the past warming and cooling periods happened over long enough time scales (tens of thousands to millions of years) that the majority of organisms were able to adapt and evolve with the changing climate. Agriculture

and permanent settlements have developed during a relatively stable climate over the last 10,000 years, which was very fortunate for humans.

However, current climate changes have happened within the last 100 years, much too rapidly for many organisms to adapt, and faster than in the last 1.2 million years.

Greenhouse Gas Concentrations:

The graph in Figure 6.1.1b shows that the atmospheric concentration of carbon dioxide has also risen and fallen in periodic cycles over ~100,000-year cycles. Figure 6.1.1b shows that CO_2 levels in the atmosphere have historically cycled between 180 and 300 parts per million (ppm) by volume.

Notice the relationship between temperature (Figure 6.1.1a) and carbon dioxide concentrations (Figure 6.1.1b). Simply, the greater the greenhouse gas concentration (in this case, CO2), the higher the temperatures. This is followed by a cooling phase after CO_2 concentrations reach ~300 ppm.

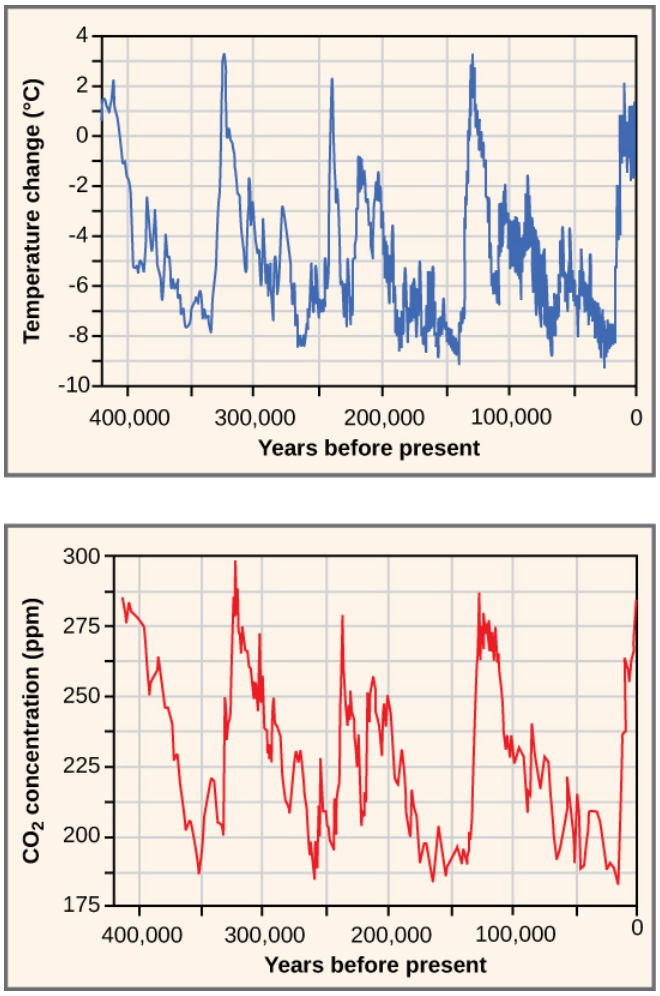


Figure 6.1.1: Ice at the Russian Vostok station in East Antarctica was laid down over the course of 420,000 years and reached a depth of over 3,000 meters. (A) Temperatures relative to modern-day were determined from the amount of deuterium (an isotope of hydrogen) present. (B) By measuring the amount of CO_2 trapped in the ice, scientists have determined past atmospheric CO_2 concentrations.

Recent Climate Variability

Figure 6.1.1 does not show the last 2,000 years with enough detail to compare the changes in Earth's temperature during the last 400,000 years with the temperature change that has occurred in the more recent past. Three significant temperature anomalies, or irregularities, have occurred in the last 2000 years. The first two are the Medieval Climate Anomaly (or the Medieval Warm Period) and the Little Ice Age. A third temperature anomaly aligns with the Industrial Era.

The **Medieval Climate Anomaly** occurred between 900 and 1300 of the Current Era (CE). During this time period, many climate scientists think that slightly warmer weather conditions prevailed in many parts of the world; the higher-than-average temperature changes varied between 0.10 °C and 0.20 °C above normal. Although 0.10°C/0.18°F does not seem large enough to produce any noticeable change, it did free seas of ice. Remember, these temperatures are global averages. Some areas became much warmer, especially at higher latitudes, and some areas remained at their same averages. Because of the warming in the higher latitudes and lack of sea ice, the Vikings were able to colonize Greenland.

The **Little Ice Age** was a cold period that occurred between 1550 AD and 1850 CE. During this time, a slight cooling of a little less than 1°C/~2°F was observed in North America, Europe, and possibly other areas of the Earth. This 1°C change in global temperature is a seemingly small deviation in temperature (as was observed during the Medieval Climate Anomaly); however, it also resulted in noticeable changes. Historical accounts reveal a time of exceptionally harsh winters with much snow and frost. These years have been immortalized in the art of Europe and colonial America, including works by Vermeer.

The **Industrial Revolution/Era**, which began around 1750, was characterized by changes in much of human society. Advances in agriculture increased the food supply, which improved the standard of living for people in Europe and North America. New technologies were invented and provided jobs and cheaper goods. These new technologies were powered by fossil fuels, especially coal. When a **fossil fuel** (coal, oil, or natural gas) is burned, CO_2 is released. With the Industrial Revolution, atmospheric CO_2 began to rise noticeably by the mid-1800s (Figure 6.1.2) and is currently at 427 ppm and rising (as compared to the average maximum of 300 ppm in the past)

The resulting rise in global temperatures has happened within the last 150 years, much too rapidly for many organisms to adapt, and faster than in the last 1.2 million years.

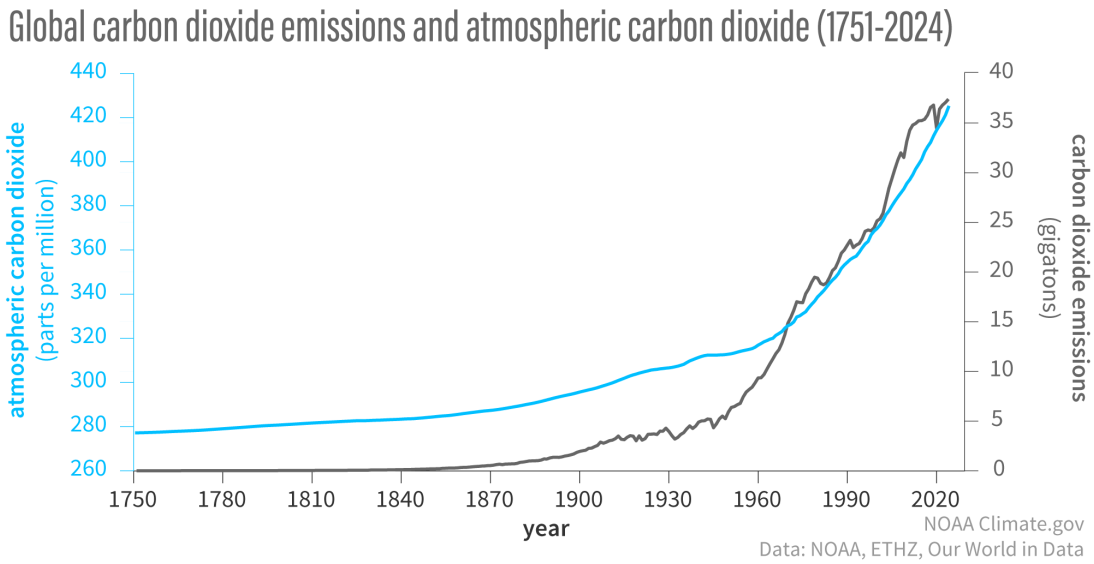


Figure 6.1.2: The amount of carbon dioxide in the atmosphere (blue line) has increased along with human emissions (gray line) since the start of the Industrial Revolution in 1750. Emissions rose slowly to about 5 gigatons (1 *gigaton* is 1 billion metric tons per year) in the mid-20th century before rapidly increasing to more than 35 billion tons per year by the end of the century. NOAA Climate.gov graph, adapted from original by Dr. Howard Diamond (NOAA ARL).

Causes of Past Climate Change

Data from the scientific evidence above indicates a strong correlation between the timing of temperature changes and **drivers**, or causes, of climate change. Before the Industrial Revolution/Era (pre-1780), there were three primary drivers of climate change not related to human activity.

1. **Milankovitch cycles**. Milankovitch cycles describe the effects of slight changes in the Earth's orbit on Earth's climate and range between 19,000 and 100,000 years. In other words, scientists expect to see predictable changes in the Earth's climate

associated with changes in the Earth's orbit within this range in the indirect evidence they gather. Note that the cycles in Figure 6.1.1 are approximately 100,000 years long!

2. **Solar intensity:** Variation in solar (the sun's) intensity is the second natural factor responsible for climate change. The amount of solar power or energy the sun emits in a given amount of time directly impacts Earth's temperature. As solar intensity increases (or decreases), the Earth's temperature correspondingly increases (or decreases). Changes in solar intensity have been proposed as one of several possible explanations for the Little Ice Age.
3. **Volcanic eruptions:** Volcanic eruptions generally last only a few days, but the solids and gases released can influence the climate for years, causing short-term climate changes. The gases and solids released include greenhouse gases and aerosols, among others. Generally, volcanic eruptions cool the climate due to the immense amount of aerosols, water vapor, and other gases that reflect light back into space. In 1783, Icelandic volcanoes erupted and released large volumes of sulfuric oxide. This led to **haze-effect cooling**, a global phenomenon that occurs when dust, ash, or other suspended particles block out sunlight and trigger lower global temperatures for 1+ years. In Europe and North America, haze-effect cooling produced some of the lowest average winter temperatures on record in 1783 and 1784. It is thought that increased global eruptions and decreased solar intensity may have been the drivers of the Little Ice Age.

Results of Past Climate Change

Climate change is not a new phenomenon. Scientists have geological evidence of the consequences of long-ago climate change. Increased global temperatures and greenhouse gases have been associated with at least one planet-wide extinction event during the geological past. The Permian extinction event occurred about 251 million years ago toward the end of the roughly 50-million-year-long geological time span known as the Permian period. This geologic time period was one of the three warmest periods in Earth's geologic history. Scientists estimate that more than 90 percent of all life became extinct near the end of the Permian period. Organisms that had adapted to wet and warm climatic conditions, such as annual rainfall of 300–400 cm and 20 °C–30 °C in the tropical wet forest, may not have been able to survive the Permian climate change.

During the past 2 million years, there have been at least 10 cycles of natural warming and cooling on a planetary scale. When the polar ice caps melted during warming periods, sea levels rose to well above their earlier levels, and a larger portion of Earth experienced tropical climates. During cooling periods, the polar ice caps expanded, sea levels dropped, and tropical species' ranges contracted. Sometimes these changes occurred gradually, which enabled the affected species to adapt. But the onset of some climate change periods was abrupt, causing major ecosystem disruptions and global mass extinction events. Yet, nature recovered every time; many of the species we see today are survivors of previous climate change events. It is thus fair to ask why today's climate change is of such concern to us.

Video



A look at the history of climate change on Earth can give us some much-needed perspective on our current climate dilemma because, the surprising truth is, what we are experiencing now is different than anything this planet has encountered before. This 11-minute video gives an overview of Earth's prior climates.
Question after watching: In what way is the current climate change different than historical climate changes?

Climate Change's Impact on Humans (Past and Present)

History provides us with many lessons to illustrate the impact of climate change on human societies. These lessons start with the earliest well-documented example of a societal collapse—that of the Middle East's Natufian communities roughly 10,000 years ago—which has been attributed to climatic changes. Since then, climate change has regularly contributed to the collapse of complex human societies across the world. Notable examples of such collapses include the Akkadian Empire (the world's first empire) of the Middle East, Egypt's Old Kingdom (the builders of the pyramids), Central America's Classic Mayan civilization, the first English colony in America, several Chinese dynasties, and the Late Bronze Age societies along the Mediterranean Sea. Also, in Southern Africa, the fall of the Mapungubwe Kingdom has been attributed to crop failures and declining grazing lands due to regional droughts and warming cycles.

Similar patterns hold true today, only on a global scale. Because of humans' collective lack of response in addressing the drivers of climate change, more people will suffer the consequences than will not. Prominently, many parts of the world are already seeing higher temperatures and longer droughts. These conditions are compromising our quality of life by leading to more intense wildfires, increased incidences of vector-borne disease, increased crop failures, and increased competition for water. Many coastal areas are also seeing storms increasing in intensity and frequency, exposing people living near large rivers, deltas, and estuaries to more frequent flooding and storm surges. For example, the impacts from Cyclone Idai, one of the worst storms on record to have hit Africa, led to the deaths of more than 1,000 people (Figure 6.1.3). While no single flooding event can be attributed to climate change, it is undeniable that warmer oceans create conditions for hurricanes and cyclones to be stronger, bigger, and more frequent. Sea level rise is expected to leave many low-lying oceanic islands uninhabitable within a few decades. With all these impacts expected to increase the competition for space under an increasing human population, it would be wise for the world's governments to start preparing for millions of climate refugees that need to be relocated soon.

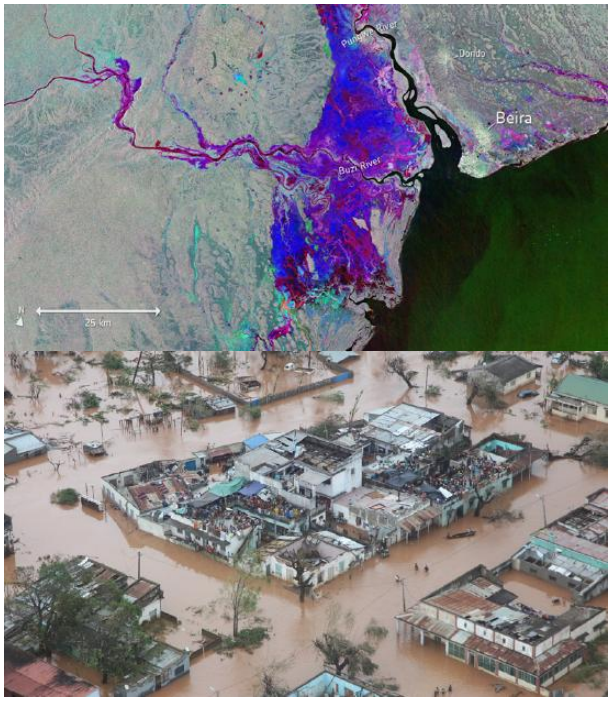


Figure 6.1.3: (Top) A Copernicus Sentinel-1 satellite image showing the extent of flooding (areas shown in blue) in central Mozambique after Cyclone Idai made landfall on 15 March, 2019. Photograph by European Space Agency, https://www.flickr.com/photos/europeanspaceagency/47477652401, CC BY-SA 2.0. (Bottom) People in Beira, Mozambique, taking refuge on rooftops to escape flooding brought by Cyclone Idai. Photograph by World Vision, https://www.flickr.com/photos/dfid/46570320385, CC BY 2.0.

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Anthropogenic Climate Change

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 2 hours.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Identify the historical beginnings of anthropogenic climate change
- Explain how current climate change is measured
- Describe the scientific consensus on anthropogenic climate change
- Identify human impacts on specific greenhouse gases

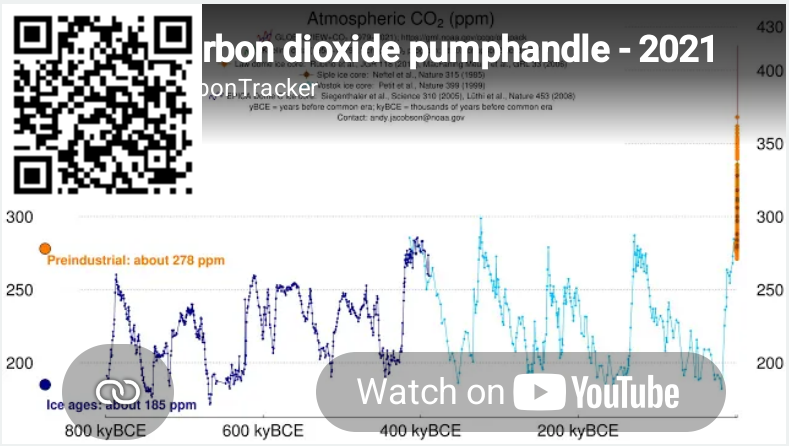
Introduction

As was detailed in the prior section, scientific evidence supports the relationship between atmospheric CO_2 and temperature: as CO_2 rises, global temperature rises.

Since 1950, the concentration of CO_2 has increased from about 280 ppm to 382 ppm in 2006.

In 2025, global CO_2 levels were 427 ppm.

Video



This 2.5-minute video shows how atmospheric CO_2 has varied recently and over the last 800,000 years, as determined by many CO_2 monitoring stations (shown on the insert map). It is also instructive to watch CO_2 variation by latitude. This shows that most of the sources of CO_2 are in the Northern Hemisphere, where humans reside.

Question after watching: What general trends do you notice over the last 800,000 years? How is the current climate breaking those trends?

Anthropogenic Climate Change

The prior section noted the three primary drivers of historical climate change: Milankovic cycles, solar intensity, and volcanic eruptions.

Today, however, human-emitted greenhouse gases are the most significant drivers of climate change.

Anthropogenic climate change refers to the impacts of humans on the climate system. Scientists generally look to the Industrial Era as the beginning of anthropogenic climate change, due to the use of fossil fuels starting in the mid-1700s. Some climate scientists argue that anthropogenic climate change actually begins *much earlier* than the Industrial Era and that humans began impacting the climate through deforestation and land clearing to grow food thousands of years ago, including farming grains in Europe and the Fertile Crescent during the first Agricultural Revolution ~8,000 years BCE, and developing artificial wetlands for rice cultivation in Asia ~5,000 years BCE. Clearing vegetation for crops is a type of **climate-forcing**, meaning greenhouse gases (e.g., CO_2) are being released. Agricultural crops store much less CO_2 than the original forests. Creating wetlands is also a carbon source due to the bacterial decay of organic matter within wetlands that produces methane.

However, it is not important whether anthropogenic climate change started with the Agricultural Revolution or the Industrial Revolution because the really significant climate changes did not start until the early 1900s (Figure 6.2.1). Human activities and population size are intertwined. As noted in Unit 5, as more and more of the world's population adopts a resource-intensive lifestyle, climate change becomes worse. These lifestyles currently require fossil fuels, which provide relatively cheap and abundant energy.

For the past 100 years, the temperature has increased at a relatively steady and rapid rate, especially compared to historical warming. The average temperature on land and on the sea's surface now is slightly more than 1.0°C higher than it was before 1750. 67% of this warming has occurred since 1975.

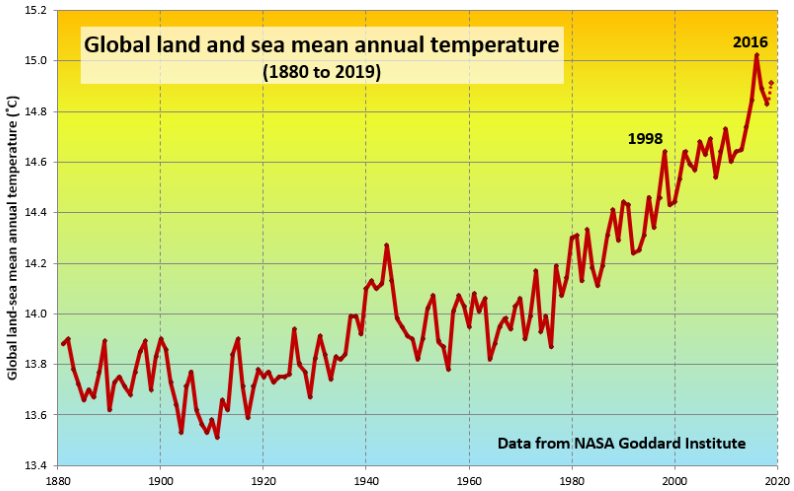
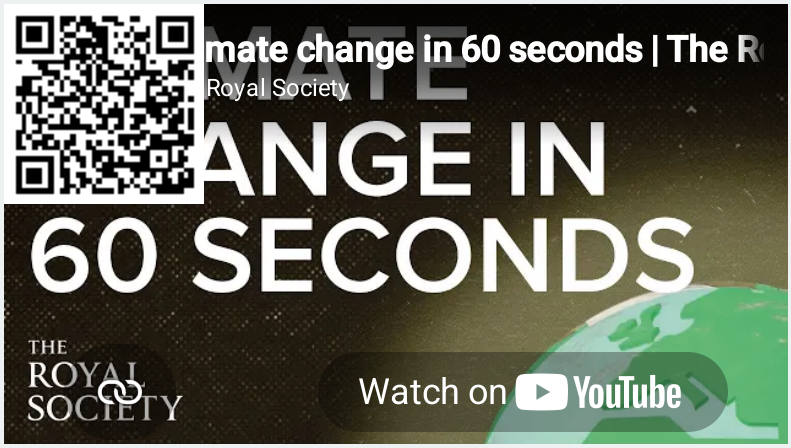


Figure 6.2.1: Global mean annual temperatures for the period from 1880 to 2019. The value for 2019 is projected, based on only 6 months of data. 1998 and 2016 were strong El Niño years. © Steven Earle. CC BY. Based on data from NASA.

Video



This 60-second animation from two of the world's leading science academies brings you the science behind climate change.

Question after watching: Of the graphs shown, which had you seen before (similar or the same)? Which ones were new to you? What does this make you think about?

How Do We Know? Measuring Current Climate Change

Changes in land surface or ocean surface temperatures can be expressed as temperature **anomalies**. A temperature anomaly is a difference in average temperature measurement from a predetermined datum (or baseline). This datum is the average temperature of a particular date range, for example, 1951 to 1980. Another common datum is the last century (1900-2000). Therefore, an anomaly of 1.25 ℃ for 2015 (last century datum) means that the average temperature for 2015 was 1.25 ℃ greater than the 1900-2000 average. In 1950, the temperature anomaly was -0.28 ℃, so this is -0.28 ℃ lower than the 1900-2000 average [3]. These temperatures are annual average surface temperatures. Figure 6.2.2 shows the global mean temperature estimates for the period of 1880 to 2020 using the datum of the 1951-1980 average temperature.

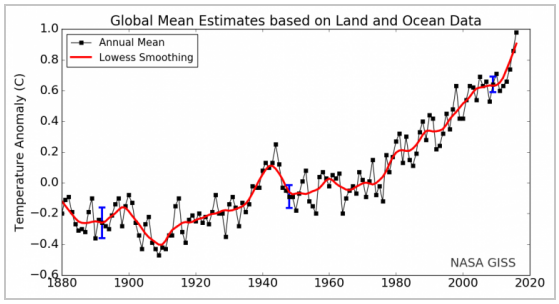


Figure 6.2.2: Land-ocean temperature index, 1880 to present, with a base time 1951-1980. The solid black line is the global annual mean and the solid red line is the five-year lowess smooth curve. The blue uncertainty bars (95% confidence limit) account only for incomplete spatial sampling.
[From https://opengeology.org/textbook/15-...limate-change/ Adapted from *Source: National Climate Data Center*]

Other valuable insights have been obtained by running sophisticated mathematical global **climate models** on high-powered supercomputers. These "virtual experiments" examine the potential climatic responses to increases in atmospheric CO_2. These computer simulations are known as three-dimensional general circulation models (GCMs). The models simulate the complex movements of energy and mass in the global circulation of the atmosphere. They also examine the interactions of these processes with physical variables that are important aspects of climate, such as temperature and precipitation. A strong tendency that emerges from these virtual experiments is that global warming and associated climate changes are a likely consequence of the well-documented increases of CO_2 and other GHGs in the atmosphere.

Many such simulation experiments have examined the scenario of a doubling of CO_2 concentration to 800 ppm from its recent concentration of just over 400 ppm. These experiments suggest that such a doubling would result in an increase of 1°C to 4°C in the average temperature of the surface atmosphere. The intensity of warming is predicted to be greatest in high-latitude regions, where the temperature increases might be two to three times greater than in the tropics.

Warming of the lower atmosphere will be one likely change that will be caused by an increased intensity of the greenhouse effect. However, there could also be important effects that occur indirectly due to increased temperatures. The most important of these would include large-scale shifts in the patterns of atmospheric circulation. Such shifts would likely result in changes in the amounts, distribution, and seasonality of precipitation. Changes in precipitation regimes would influence soil moisture, which would greatly affect the distribution and productivity of vegetation, both natural and managed. These changes in precipitation regime would likely have much greater effects on agricultural and wild ecosystems than would any direct influence of a warmed atmosphere.

Indigenous Connections: Monitoring Climate Change

"Indigenous research methodologies are "…as old as our ceremonies and our nations. They are with us and have always been with us" (Cardinel, 2001). The methodologies for Indigenous-led research are varied across and within First Nation, Inuit, and Métis communities across Canada reflecting the diversity of worldviews and ways of knowing" (First Peoples Group, 2022).

"Many Indigenous climate monitoring projects co-apply Indigenous Knowledge Systems with science bringing together the strengths of both knowledge systems. This has been described as two-eyed seeing (Etuaptmumk in Mi'kmaw), which involves

'learning to see from one eye with the strengths of Indigenous Knowledges and ways of knowing, and from the other eye with the strengths of mainstream knowledges and ways of knowing, and to use both these eyes together, for the benefit of all' (Marshall, 2020)" (First Peoples Group, 2022).

"Indicators are used by many Indigenous Peoples to understand and communicate about ecological change. They are the signs and signals that have guided understanding and decisions within Indigenous communities for hundreds if not thousands of years. Climate indicators can relate to:

- radiation (solar radiation or sunlight; surface temperature and thermal radiation)
- the atmosphere (e.g., temperature, precipitation, wind, humidity);
- the land (e.g., changes in permafrost, soil moisture, soil temperature, water-table depth)
- water quantity (e.g., flow, water depth) or quality (e.g., pH, dissolved oxygen, nitrate, phosphates, water temperature)
- ice and snow (e.g., timing of ice formation and breakup, thickness, quality; snow depth)
- plants and animals (e.g., timing of arrival of species, species population and distribution, health and body condition, taste and yield of berries, spectroscopy)" (First Peoples Group, 2022).

"Elders and Knowledge keepers hold invaluable knowledge about the changes to the land and the environment as a whole. Going out on the land with Knowledge holders can provide a natural space for intergenerational knowledge transfer and Indigenous Knowledge sharing. Participatory video is a newer method of documenting community climate observations and stories through mobilizing stories and collectively-held knowledge with diverse audiences to inform climate adaptation" (First Peoples Group, 2022).

"Many Indigenous climate monitoring projects also follow scientific methods for collecting data. Many monitoring projects incorporate sensors and automated instrumentation which remain in the field such as weather stations, hydrological sensors, trail cameras, soil temperature sensors, etc. Some community-based monitoring projects are even using observations from space-based remote sensors (e.g., Landsat 8, LIDAR)" (First Peoples Group, 2022).

In 2022, the federal government announced $800 million towards Indigenous-led conservation efforts, including those that help to mitigate climate change, like the BC Northern Shelf Bioregion: https://pm.gc.ca/en/news/news-releases/2022/12/07/protecting-more-nature-partnership-indigenous-peoples

Sources:

Cardinel, L. 2001. What is an Indigenous Perspective? Canadian Journal of Native Education, 25(2), 180-182.

Elder Dr. Albert Marshall from Reid, Andrea J Lauren E. Eckert, John-Francis Lane, Nathan Young, Scott G. Hinch, Chris T. Darimont, Steven J. Cooke, Natalie C. Ban, Albert Marshall. 2020. “Two-Eyed Seeing”: An Indigenous framework to transform fisheries research and management. Fish and Fisheries 22:2, p243-261. Available at: https://doi.org/10.1111/faf.12516



This beautifully illustrated animation video explains what climate change means for Tsay Keh Dene, the changes that elders have observed in their territories of British Columbia, and how these changes will impact local cultures

and traditional practices. It describes the Tsay Keh Dene and Carcross Tagish Community-Based Climate Monitoring project funded by Crown-Indigenous Relations and Northern Affairs Canada.

Scientific Consensus: Global Anthropogenic Climate Change is Real

The **Intergovernmental Panel on Climate Change** (IPCC)—established by the United Nations Environment Programme and the World Meteorological Organization in 1988—is responsible for reviewing the scientific literature on climate change and issuing periodic reports on several topics, including the scientific basis for understanding climate change, our vulnerability to observed and predicted climate changes, and what we can do to limit climate change and minimize its impacts. 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 six years. The Panel is on their most recent Synthesis Report, the 6th Assessment Report. Working group reports were released in 2021-2022. 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 according to the last IPCC assessment is clear: global climate change is real and humans are very likely the cause for this change.

Additionally, the major scientific agencies of the US government also agree that climate change is occurring and that humans are driving it. From the Third National Climate Assessment: "Global climate is changing and is apparent over a wide range of observations. The global warming over the past 50 years is primarily due to human activities." Many independent scientific organizations have released similar statements, both in the US and abroad. This does not necessarily mean that every scientist agrees on the strength of each component of the climate change system, but a nearly universal agreement exists that climate change is happening and is primarily caused by excess greenhouse gases from human activities.

Video



This 14-minute video from the IPCC summarizes much of the 6th Assessment Report on Impacts, Adaptation, and Vulnerability with a global focus.

Question after watching:

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, human activities, especially our combustion of fossil fuels, explains the current warming (Figure 6.2.3). 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.

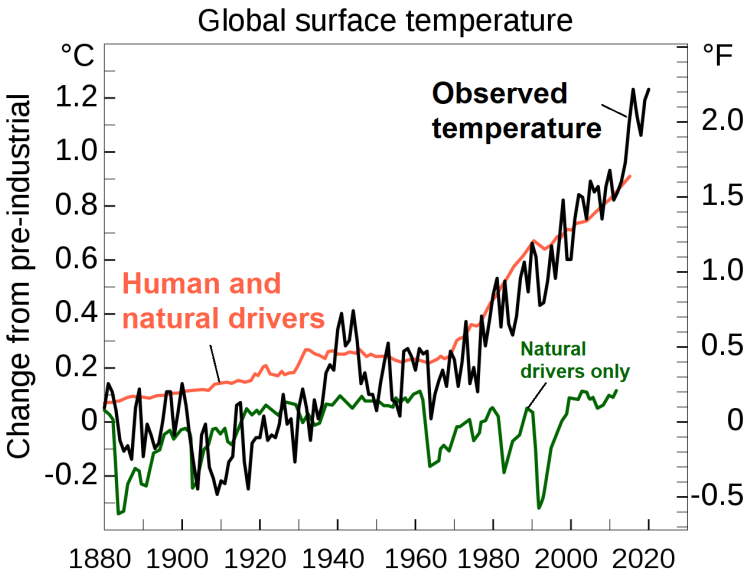


Figure 6.2.3: This graph shows the predicted temperatures from two climate models and observed temperatures from 1880 to 2020. The first model considered only natural factors that could influence temperature and is represented by the green line (bottom). It shows some fluctuations in temperature by no overall increase or decrease. The second model considered both human and natural factors and is represented by the orange line (top). It shows an overall increase in temperature. Actual observations (black, jagged line; middle) more closely match the second model. Overall, temperature has increased about 1.2°C since pre-industrial times. Image relabeled from Efbrazil CC-BY-SA.

Climate change forecasting is famously complex, with a great amount of uncertainty attached to the task. The general models used for climate change forecasting need to account for a great number of highly variable components, each affecting one another across the only planet we can adequately measure or examine (we have no other planet where we can test predictions). Among thousands of considerations, **climatologists**, scientists who study climate, need to account for how human activities might change over time, and how these activities will change the atmosphere's composition. They also need to account for how much CO_2 the world's oceans and plants will absorb, and how wind and fire might influence these processes. Combining all the component parts, climatologists then need to estimate how increased temperatures will affect the polar ice caps, how the melting ice will affect oceanic conditions and currents which, in turn, will affect terrestrial conditions and weather patterns. Uncertainty also exists over interactive effects of some drivers. For example, higher temperatures increase evaporation and cloud cover which, in turn, will have a moderate cooling effect. Because of the complexity of these and other variables going into climate models, a great number of research groups are encouraged to develop their own climate forecasts, each using a range of different scenarios on how human activity might change in the future.

By regularly doing extensive reviews of all the evidence and climate science literature, the IPCC has found that, despite the complexity of climate models, results of all the models taken together exhibited significant agreement with changes already observed. Climate change models have also proven reliable in predicting responses of biodiversity to climate change. While climatologists continue to improve on the finer details of their models, conservation biologists can and should confidently use the climate forecasts available for general conservation planning purposes.

Optional Resource

So, why is there still doubt among the general public? The largest reason: various entities and industries have a vested interest in not changing the status quo - they make a great deal of money off of fossil fuels and other polluting industries and so pay to keep doubt about climate change in the public sphere. Find out more in this award-winning Frontline investigation from 2012:

We're sorry, but there was an error playing this video. Please try again later.

Specific Human Impacts on Greenhouse Gases

Recall that GHGs are probably the most significant drivers of current climate change. The GHGs that affect Earth include carbon dioxide, methane, water vapor, nitrous oxide, and ozone. 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.



Figure 6.2.6: The burning of fossil fuels in industry and by vehicles releases carbon dioxide and other greenhouse gases into the atmosphere. (CC-BY-SA 4.0 “Pöllö”/Wikimedia Commons)

Sinks and Sources

Places in the ecosystem that store GHGs are reservoirs. Places that supply and remove are **sources** and **sinks**, respectively. If more GHGs are released than stored, the place is a source. If more GHGs are absorbed than emitted, the reservoir is a sink. A reservoir can change from a sink to a source and vice versa. For example, a forest is a sink for carbon, but when the forest burns it becomes a carbon source.

Carbon Dioxide

Carbon dioxide (CO_2) is the primary greenhouse gas that is contributing to recent global climate change. Healthy living forests and the oceans act as carbon sinks. The mantle is a natural source of carbon from volcanic gases. The link between human-induced climate change and atmospheric CO_2 concentrations was first highlighted in the late 19th century by Arrhenius. However, it was not until the mid-1950s that scientists started to raise concerns about increasing CO_2 concentrations in the atmosphere. By the 1980s, as global annual mean temperatures started to rise, consensus about climate change linked to CO_2 began to spread among the broader public. Yet concrete steps to curb CO_2 emissions have only been initiated recently.

In the meantime, CO_2 emissions continue to accelerate: more than 37 billion tonnes of carbon, a new record, were released into the atmosphere in 2018. 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, deforestation, and changes in land use, release very large amounts of CO_2 to the atmosphere, causing its concentration in the atmosphere to rise, where each molecule may remain for more than 200 years. Cement manufacture, animal agriculture, the clearing of land, and the burning of forests are other human activities that release carbon dioxide.

Scientists look at patterns in data and try to explain differences or deviations from these patterns. As stated in Unit 5.3.1, the atmospheric carbon dioxide data reveal a historical pattern of carbon dioxide increasing and decreasing, cycling between a low of 180 ppm and a high of 300 ppm (Figure 6.2.4). Scientists have concluded that it took around 50,000 years for the atmospheric carbon dioxide level to increase from its low minimum concentration to its higher maximum concentration. However, starting recently, atmospheric carbon dioxide concentrations have increased beyond the historical maximum of 300 ppm. Atmospheric CO_2 concentrations have increased by 45% since pre-industrial times, from approximately 280 parts per million (ppm) in the 18th century to 415 ppm in 2021. What is the reason for this difference in the rate of change and the amount of increase in carbon dioxide? A key factor that must be recognized when comparing the historical data and the current data is the presence of modern human society; no other driver of climate change has yielded changes in atmospheric carbon dioxide levels at this rate or to this magnitude.

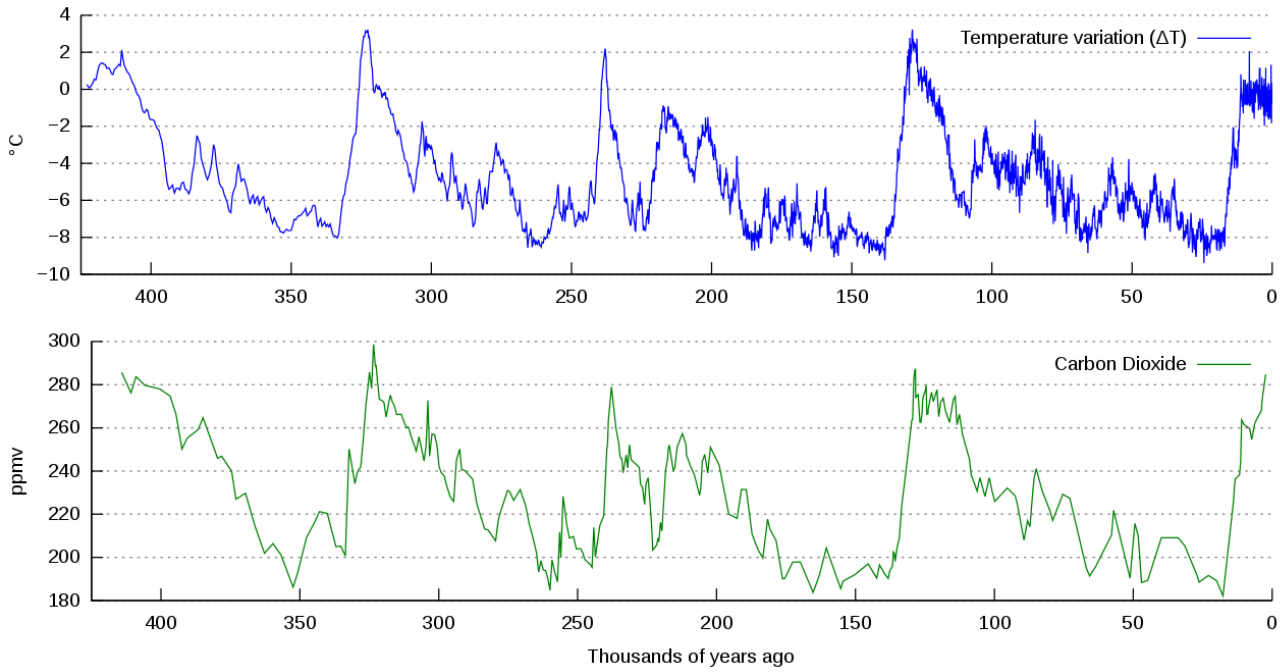
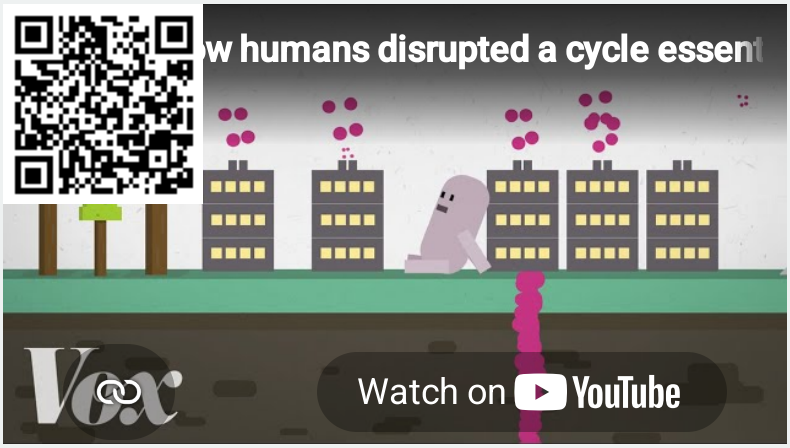


Figure 6.2.4: Graph of change in temperature in degrees Celsius (top, blue line) and carbon dioxide concentration in parts per million by volume (bottom, green line) measured from the Vostok, Antarctica ice core. These have been associated for over 400,000 years. As carbon dioxide concentration increased, so did temperature. As carbon dioxide concentration decreased, so did temperature. These data were collected in 1999. Since then, carbon dioxide concentrations have stabilized to over 410 ppm. Image and caption (modified) by NOAA/Autopilot (CC-BY-SA)

Video



This 4-minute animation describes the natural carbon cycle and how humans are disrupting that cycle. Question after watching: Which of the technologies to remove carbon from the atmosphere have you heard of before? Which have you not? What do these technologies do?

Optional Activity 6.2.2

How long does a molecule of CO_2 remain in the atmosphere?

A. CO_2 washes out of the atmosphere seasonally.
B. CO_2 remains in the atmosphere for 5-10 years.
C. CO_2 remains in the atmosphere for up to 200 years, or more.

Answer

C. CO_2 remains in the atmosphere for up to 200 years, or more.

Video



Earth's atmosphere naturally contains greenhouse gases. Without them, the world would be way too cold for humans. But we are adding extra greenhouse gases, which are causing Earth to heat up and disrupting weather patterns worldwide. So which of these many gases is heating Earth the most?

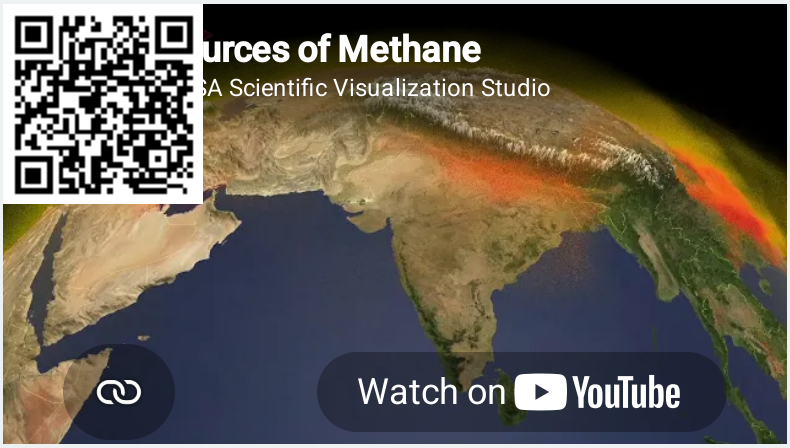
Methane

Although this concentration is far less than that of CO_2, **methane** (CH_4) is 28 times as potent a greenhouse gas. Methane is produced when bacteria break down organic matter under anaerobic conditions and can be released due to natural or anthropogenic

processes. Anaerobic conditions can happen when organic matter is trapped underwater (such as in rice paddies) or in the intestines of herbivores. Anthropogenic causes now account for 60% of total methane release. Examples include agriculture, fossil fuel extraction and transport, mining, landfill use, and burning of forests. Methane can also be released from natural gas fields and the decomposition that occurs in landfills. Specifically, raising cattle releases methane due to fermentation in their rumens producing methane that is expelled from their GI tract. Methane is more abundant in Earth's atmosphere now than at any time in at least the past 650,000 years, and CH_4 concentrations increased sharply during most of the 20th century. They are now more than 2.5 times pre-industrial levels and increasing rapidly.

Another source of methane is the melting of clathrates (methane hydrate). **Clathrates** are frozen chunks of methane hydrate found at the bottom of the ocean. When water warms these chunks of ice melt and methane is released. As the ocean's water temperature increases, the rate at which clathrates melt is increasing, releasing even more methane. This leads to increased levels of methane in the atmosphere, which further accelerates the rate of global warming. This is an example of the positive feedback loop that is leading to the rapid rate of increase in global temperatures. There is strong evidence that warming during the Quaternary period 55 million years ago was caused, at least in part, by a massive release of clathrates.

Video



This 2-minute, 3D volumetric visualization shows the emission and transport of atmospheric methane around the globe between December 9, 2017 and December 1, 2018. (NASA)

Question after watching: What patterns do you notice based on the narrator's descriptions and the visualization?

Video



Beef production emits more greenhouse gases than basically anything else we eat, so let's look at the scale and impact of our bovine pals - and importantly, what we can actually do to make beef less bad.

Other Greenhouse Gases

Nitrous oxide (N_2O) is produced through natural and human activities, mainly through agricultural activities and natural biological processes. Fuel-burning and some other processes also create N_2O. Concentrations of N_2O have risen approximately 18% since the start of the Industrial Revolution, with a relatively rapid increase towards the end of the 20th century. [3] In contrast, the atmospheric concentration of N_2O varied only slightly for a period of 11,500 years before the onset of the industrial period, as shown by ice core samples.

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. In addition to trapping heat, ozone is a pollutant that can cause respiratory health problems and damage crops and ecosystems.

Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), together called **F-gases**, are often used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Unlike water vapor and ozone, these F-gases have a long atmospheric lifetime, and some of these emissions will affect the climate for many decades or centuries.

Human-Induced Changes in Albedo and Aerosols

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. In addition, human activities have generally increased the number of aerosol particles in the atmosphere. Overall, human-generated aerosols have a net cooling effect offsetting about one-third of the total warming effect associated with human greenhouse gas emissions. Reductions in overall aerosol emissions can therefore lead to more warming. However, targeted reductions in black carbon emissions can reduce warming.

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.

Video



This 2-minute video visualizes albedo.

Question after watching: What are some human activities that change albedo as visualized in the video?

Climate Feedbacks

When sea ice melts, as it has done in the Arctic Ocean at a disturbing rate over the past decade, the albedo of the area affected changes dramatically, from around 80% down to less than 10%. This is a positive feedback (see a review of feedback loops in Unit 4.4.1) because much more solar energy is absorbed by the water than by the pre-existing ice, and the temperature increase is amplified. The same applies to ice and snow on land, but the difference in albedo is not as great.

When ice and snow on land melt, sea level rises. Sea level is also rising because the oceans are warming and that increases their volume. A higher sea level means a larger proportion of the planet is covered with water, and since water has a lower albedo than land, more heat is absorbed and the temperature goes up a little more. Since the last glaciation, sea-level rise has been about 125m; a huge area that used to be land is now flooded by heat-absorbent seawater. During the current period of anthropogenic climate change, sea level has risen only about 20 cm, and although that does not make a big change to albedo, sea-level rise is accelerating.

Video



A warming Arctic can catapult the world into drastic climate impacts through feedback loops as seen in this 3.5-minute video.

Question after watching: Why should we be concerned with permafrost melting as well as ice in the Arctic?



Figure 6.2.10: A degrading permafrost site on the north coast of Alaska.

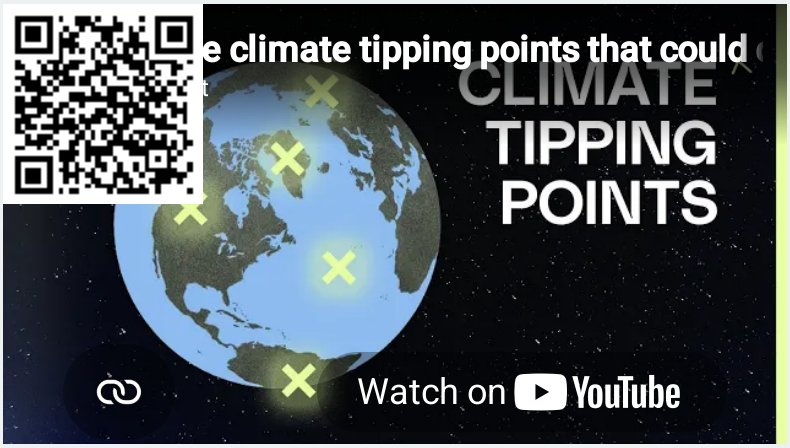
Most of northern Canada has a layer of permafrost that ranges from a few centimeters to hundreds of meters in thickness; the same applies in Alaska, Russia, and Scandinavia. Permafrost is a mixture of soil and ice (Figure 6.2.10), and it also contains a significant amount of trapped organic carbon that is released as CO_2 and CH_4 when the permafrost breaks down. Because the amount of carbon stored in permafrost is in the same order of magnitude as the amount released by burning fossil fuels, this is a feedback mechanism that has the potential to equal or surpass the forcing that has unleashed it. In some polar regions, including northern Canada, permafrost also includes methane hydrate. Breakdown of permafrost releases this form of methane.

There is about 45 times as much carbon in the ocean (as dissolved bicarbonate) as there is in the atmosphere (as CO_2), and there is a steady exchange of carbon between the two reservoirs. But the ability of CO_2 to dissolve in water (its **solubility**) decreases as the temperature goes up. In other words, the warmer it gets, the more oceanic bicarbonate gets released to the atmosphere as CO_2. That makes CO_2 solubility another positive feedback mechanism.

Vegetation growth responds positively to both increased temperatures and elevated CO_2 levels, and so in general, it represents negative feedback to climate change because the more the vegetation grows, the more CO_2 is taken from the atmosphere. However, trees grow bigger and more vigorously so forests have lower albedo so they absorb more heat. In addition, climate change is not just more CO2, it may mean more or less rain, extreme weather events, or drastic seasonal changes that interfere with forest health. Furthermore, climate warming isn't necessarily good for vegetation growth; some areas have become too hot, too dry, or even too wet to support the plant community that was growing there, and it might take centuries for something to replace it successfully.

All of these positive (and negative) feedbacks work both ways. For example, during climate cooling, growth of glaciers leads to higher albedos, and formation of permafrost results in storage of carbon that would otherwise have returned quickly to the atmosphere.

Video



This 3.5-minute video describes climate tipping points.
Question after watching: What is meant by a "tipping point" for climate? What types of systemic changes are studied in terms of climate tipping points? Are these positive feedbacks or negative feedbacks?

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6.3: Current and Future Climate Change Impacts

Current and Future Climate Change Impacts

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- Bolded terms are located at the end of the unit in the Glossary. There is also a Unit Summary at the end of the Unit.
- To navigate to Unit 5.3.4, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Identify current global climate impacts and their confidence level
- Explain several projected abiotic climate impacts and their effects on living organisms

Introduction

Climate change has the potential to render Earth unrecognizable from what any human has ever experienced. These changes will have an immense impact on ecosystem services, global economies, and our own quality of life. Yet, while there is much talk about these risks, there is still too little action addressing its main causes.

Current Climate Change Impacts

Some of the lack of action may be attributed to “climate change” and “future” often being used in the same sentence, giving politicians and industries a false impression that we can deal with climate change once we achieved sufficient economic growth. The reality could however not be further from the truth, as we already see signs of the changes to come here today (Table 6.3.1), including near-annual crop failures, record-high temperatures, and record-strength coastal storms.

Table 6.3.1: Some examples illustrating how climate change is already impacting our planet (IPCC, 2022).

Impact	Evidence
Increased extreme weather	The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt. (high confidence). Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought, and fire weather (high confidence).
Widespread flood and droughts	Flood and drought-related acute food insecurity and malnutrition have increased in Africa (high confidence) and Central and South America (high confidence).
Rising sea levels	Continued and accelerating sea level rise will encroach on coastal settlements and infrastructure (high confidence) and commit low-lying coastal ecosystems to submergence and loss (medium confidence).
Earlier spring activity	Widespread deterioration of ecosystem structure and function, resilience, and natural adaptive capacity, as well as shifts in seasonal timing have occurred due to climate change (high confidence), with adverse socioeconomic consequences (high confidence).
Disease spread	The occurrence of climate-related food-borne and water-borne diseases has increased (very high confidence). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (high confidence). Animal and human diseases, including zoonoses, are emerging in new areas (high confidence).
Shifts in species ranges	Approximately half of the species assessed globally have shifted polewards and to higher elevations on land (very high confidence).
Wildlife population declines	Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (high confidence). The extent and magnitude of climate change impacts are larger than estimated in previous assessments (high confidence). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (high confidence), as well as mass mortality events on land and in the ocean (very high confidence) and loss of kelp forests (high confidence). Some losses are already irreversible, such as the first species extinctions driven by climate change (medium confidence).

Terms from Table 6.3.1

Risk: provides a framework for understanding the increasingly severe, interconnected, and often irreversible impacts of climate change on ecosystems, biodiversity, and human systems; differing impacts across regions, sectors, and communities; and how to best reduce adverse consequences for current and future generations.

Adaptation: in human systems, the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate

and its effects; human intervention may facilitate this.

Resilience: the capacity of social, economic, and ecosystems to cope with a hazardous event, trend, or disturbance, responding, or reorganizing in ways that maintain their essential function, identity, and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning, and transformation.

Mitigation: reducing emissions, and stabilizing the levels, of heat-trapping greenhouse gases in the atmosphere.

Confidence: each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high.

Between June 25 and July 1, 2021, British Columbia experienced a massive heat dome with temperatures reaching 49.6^{o}C in some areas. Scientists have stated that climate change was a contributing factor. More than 500 deaths were attributed to the heat. Glaciers throughout British Columbia are in retreat, with losses ranging from 6% to 34% from 1985-2005, and their melting is increasing. See more from the British Columbia Provincial Government: Change in Size of B.C. Glaciers.

A summary of the impacts of climate change on natural disasters is given in Figure 6.3.1. The major types of disasters related to climate are floods and storms, but the health implications of extreme temperatures are also becoming a great concern. In the decade 1971 to 1980, extreme temperatures were the fifth most common natural disasters; by 2001 to 2010, they were the third most common.

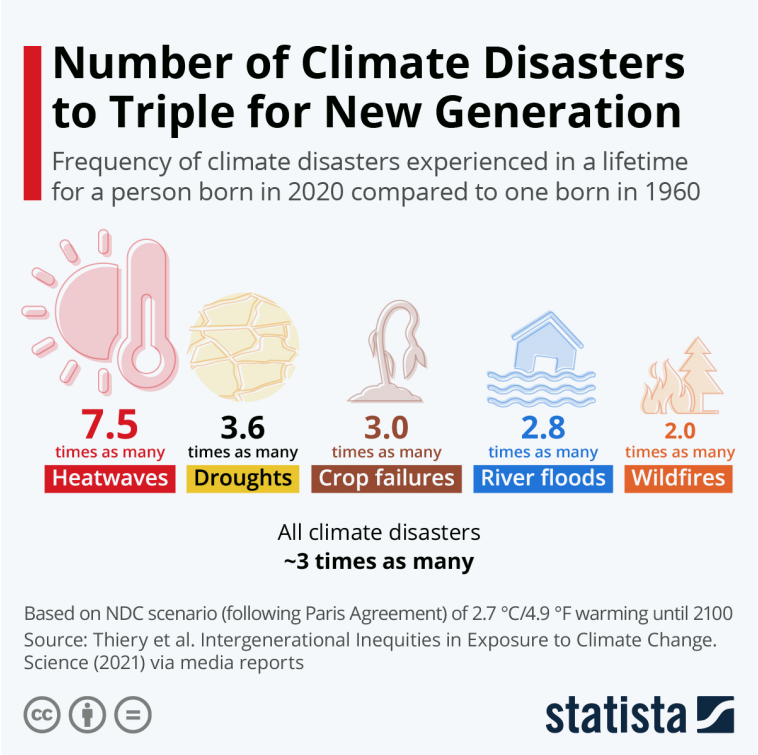


Figure 6.3.1: Predicted future climate disasters for someone born in 2020 versus someone born in 1960.

Video



It's impossible to say that climate change is responsible for any individual storm or hurricane, but climate change is making these storms stronger.

Future Climate Change

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 (Figure 6.3.3). 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. Thus, past and present GHG emissions will affect climate far into the future.

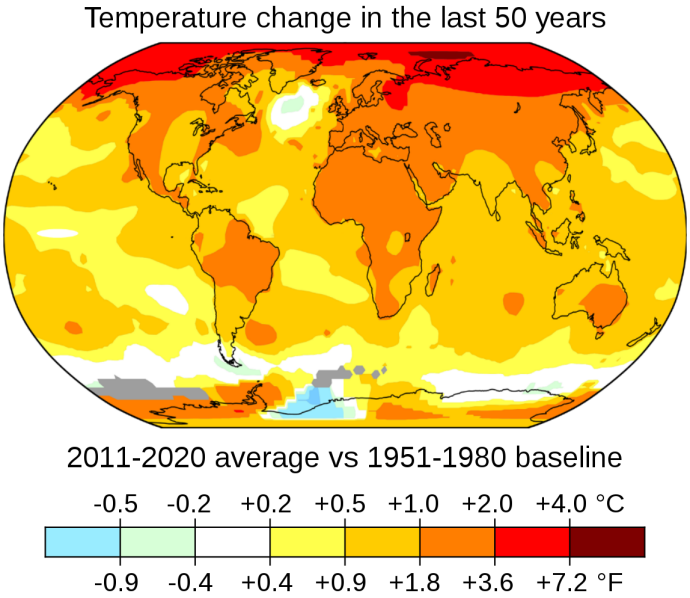


Figure 6.3.3: Temperature increases have been most pronounced in northern latitudes and over land masses. The colors represent the temperature difference between the 2011-2020 average and the 1951-1980 baseline, with warmer colors (yellow, orange, red) representing increases, and cool colors (green, blue) representing decreases. The image uses longer term averages of at least a decade to smooth out climate variability due to factors such as El Niño. Grey areas in the image have insufficient data for rendering. Image and caption (modified) from NASA's Scientific Visualization Studio/Eric Fisk (public domain).

Temperature Changes

Climate models project the following key temperature-related changes:

- Average global temperatures are expected to increase by 1.1°C to 6.4°C 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.

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, often known as "climate scenarios" (Figure 6.3.4);
- How strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected increase in greenhouse gas concentrations; and
- 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).

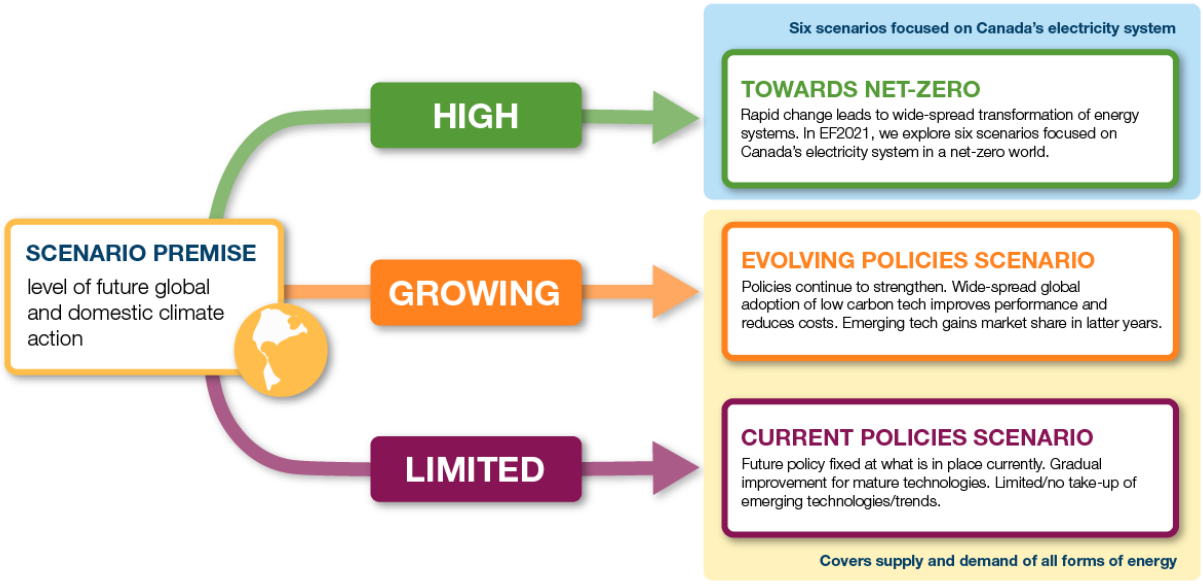


Figure 6.3.4: Conceptual illustration of Canada's energy and climate scenarios, 2021. The first main scenario is the Evolving Policies Scenario. The premise of this scenario is that there is *growing* action to reduce the GHG emissions from our energy system at a pace similar to recent history, in both Canada and the world. Relative to a scenario with less action to reduce GHG emissions, this projection implies less global demand for fossil fuels, and greater use of low-carbon technologies. The second main scenario is the Current Policies Scenario, which assumes *limited* action to reduce GHGs beyond policies already in place today. The third main set of scenarios explores a net-zero future with a *high* level of global and domestic climate action. Specifically, the set of scenarios in the Net-Zero premise explore what Canada's electricity grid might look like in a net-zero world under six different sets of assumptions about future technologies, climate policies, and electricity use. (Government of Canada - Canada Energy Regulator)

Species that are highly mobile are not entirely spared from the negative impacts of climate change. Consider that migratory species rely on environmental cues, such as day length and temperature, to determine when to start moving from one area to the next. But because different species rely on different environmental cues to time their life cycles (e.g. breeding), not all species will adjust to climate change at the same rate. There is consequently a high likelihood that climate change will disrupt these synchronous movements that the animals in particular have developed over thousands to millions of years. This disruption of timed aspects of a species' life cycle, such as migration and breeding, is called **phenological mismatch**. Researchers have already seen signs of phenological mismatch: some migratory birds that overwinter in the tropics have started to migrate to their breeding grounds at earlier dates than before. If these trends hold, they may soon start breeding before peak food availability, which could lead to lower fitness of offspring.

Resident species are also vulnerable to phenological mismatch. While these species might not be known for large-scale movements around the globe, they may still have to adjust their ranges to keep track of their climatic niches. Considering the improbability that different species will all adapt at the same pace, there is thus a danger that important mutualistic relationships might be pulled apart during these range adaptations. This is of concern for species with specialized feeding niches, as seen in some pollinators. Extinctions arising from this decoupling of mutualistic relationships are referred to as **coextinction**.

Freshwater ecosystems will generally experience temperature increases under climate change. Like their terrestrial counterparts, many freshwater species are sensitive to temperature shifts as warmer water also holds less dissolved oxygen. In addition, longer growing seasons and higher water temperatures will lead to increased nutrient loads, algae blooms, and eutrophication. All these factors will force many freshwater species—even those not sensitive to temperature shifts—to adjust their ranges to keep track of suitable conditions. For some freshwater species, the impediments to adjusting their ranges as necessary may be insurmountable.

Not all species will be impacted negatively. A variety of species are expected to benefit from climate change. These include generalist species currently limited by interactions with localized specialists that are—at least at present—better competitors for limiting resources. Some tropical species may thrive as their habitats become hotter and wetter. Species with high genetic diversity that reproduce quickly (allowing for rapid adaption to environmental changes) are also likely to benefit. Unfortunately, many species that exhibit these traits carry diseases and/or are agricultural pests. For example, populations of the coffee berry borer (*Hypothenemus hampei*)—Africa's most notorious coffee pest—are expected to greatly increase in a warmer world. This growing threat is particularly worrying given that higher temperatures have already reduced coffee harvests in countries such as Tanzania by as much as 50%.

The range of disease-carrying insects and the viruses and pathogenic parasites they harbor will increase. This spread has already been documented in North America with several different diseases including West Nile and Lyme disease. 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, but increasing temperatures will also accelerate the host lifecycles, allowing them to breed and multiply more quickly. They may even evolve pesticide resistance faster. In addition to those listed above, other diseases such as dengue fever, malaria, yellow fever, zika virus, and chikungunya are expected to spread to new regions as the global climate warms.

Climate change does not only increase the spread of diseases in humans. Rising temperatures are associated with greater amphibian mortality due to chytridiomycosis (see Unit 5.2.3). Similarly, warmer temperatures have exacerbated bark beetle infestations of coniferous trees, such as pine and spruce.

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. Because warm air is able to hold more water than cold air, the general global trend over the past century has been one of increasing precipitation (Figure 6.3.5).

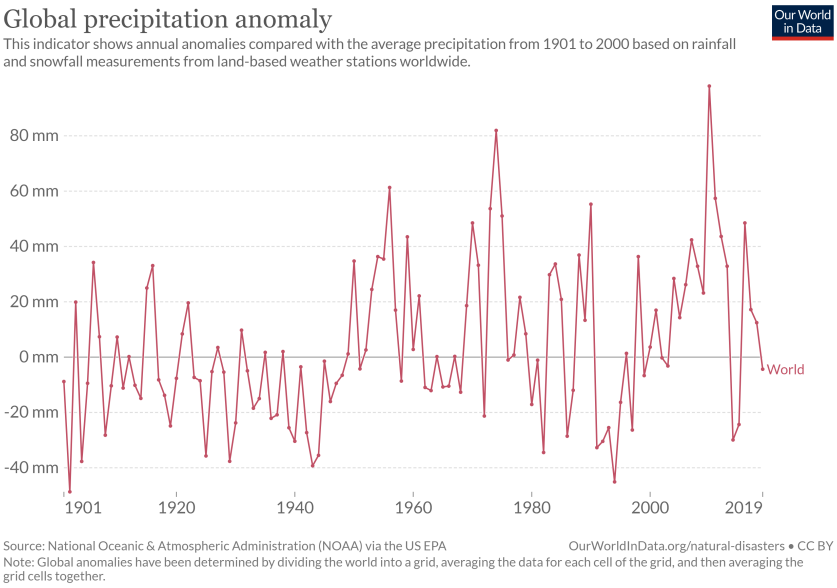


Figure 6.3.5: Data shows global precipitation patterns, based on rainfall and snowfall measurements from land-based weather stations worldwide. This indicator shows annual anomalies, or differences, compared with the average precipitation from 1901 to 2000. CC-BY United States Environmental Protection Agency (EPA)

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 toward 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.

One of the other risks for coastal populations, besides sea-level rise, is that climate warming is also associated with an increase in the intensity of coastal storms (e.g., atmospheric rivers, hurricanes, cyclones, or typhoons), which almost always bring serious flooding from intense rain and storm surges. Some recent examples are the Vancouver floods of 2021 and the impact of Hurricane Fiona on Nova Scotia in 2022 (Figure 6.3.6).



Figure 6.3.6: Grounded barge along Vancouver's Seawall in English Bay. November 2021. CC-BY-SA 4.0 Northwest

Changing precipitation levels will have several impacts on freshwater ecosystems, particularly as it relates to changes in their flow regimes. For example, areas that are undergoing decreased precipitation will experience decreased runoff and increased drying of wetlands and small streams, while areas with increased precipitation will experience increased storm surges and flushing. Given these multiple stressors, there is a reasonable expectation that many freshwater species will go extinct or face significant population declines and range shifts over the next decades. These changes are of major concern in countries that are currently majority subsistence, where so many people depend on fish and related natural resources for their livelihoods. Many communities around the world are already finding it more difficult to meet their nutritional needs due to climate-induced freshwater fish declines. Also, at some large lakes, which may supply 20–40% of the surrounding countries' dietary protein—fish yields have decreased by 30% in recent years, also attributed to climate change.

Ice Melt and Sea Level Rise

Arctic sea ice is already declining. Sea ice is ice floating in the ocean (not on land like a glacier). Most sea ice is in the Arctic Ocean and the extent of sea ice is shrinking. Below, the NOAA animation shows how perennial sea ice has declined from 1990 to 2015. The oldest ice is white and the youngest (seasonal) ice is dark blue. The amount of old ice has declined from 20% in 1985 to 3% in 2015. For every 1°C of warming, models project about a 15% decrease in the extent of annually averaged sea ice (the total ice extent and concentration averaged over a year) and a 25% decrease in September Arctic sea ice.

Video



This 2-minute video from the US's National Oceanic and Atmospheric Association illustrates the loss of Arctic sea ice from 1990-2015.

Question after watching: What seasonal patterns do you notice? What do you notice regarding the oldest ice over the 25 years portrayed in the video?

The land-based, coastal sections of the Greenland and Antarctic ice sheets have been melting significantly and are expected to continue to do so (Figure 6.3.7). If the rate of this ice melting increases in the 21st century, these ice sheets could add significantly to global sea level rise and disrupt global ocean currents. Before anthropogenic warming, glacial activity was variable with some retreating and some advancing. Now, nearly all glaciers globally a retreating and expected to continue to melt, leading to freshwater shortages globally.

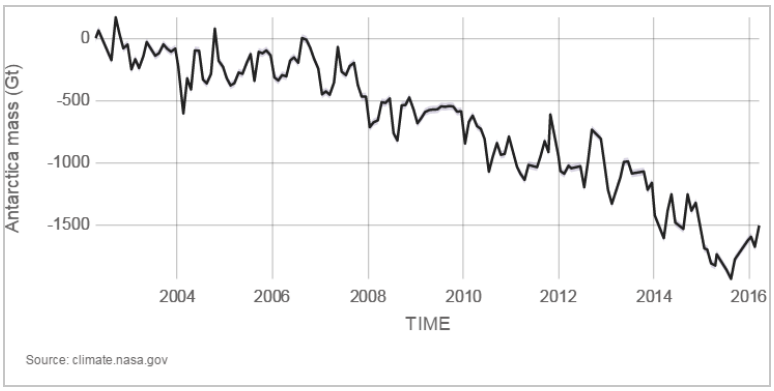


Figure 6.3.7: Decline of Antarctic ice mass from 2002 to 2016. (NASA)

On average, the sea is rising at a rate of 1.8 mm per year. However, between 1993 and 2010 the rate of sea level increase ranged between 2.9 and 3.4 mm per year (Figure 6.3.8). This is thought largely to be from both the melting of glaciers and thermal expansion. Thermal expansion means that as objects such as solids, liquids, and gases heat up, they expand in volume. Since 1970, the melting of glaciers and thermal expansion account for 75% of the sea-level rise (scientists are still researching the other 25%). As the oceans creep further inland, the extent of low-lying coastal ecosystems such as rocky shores or sandy beaches will shrink, and so also the sizes of the wildlife populations living in those areas.

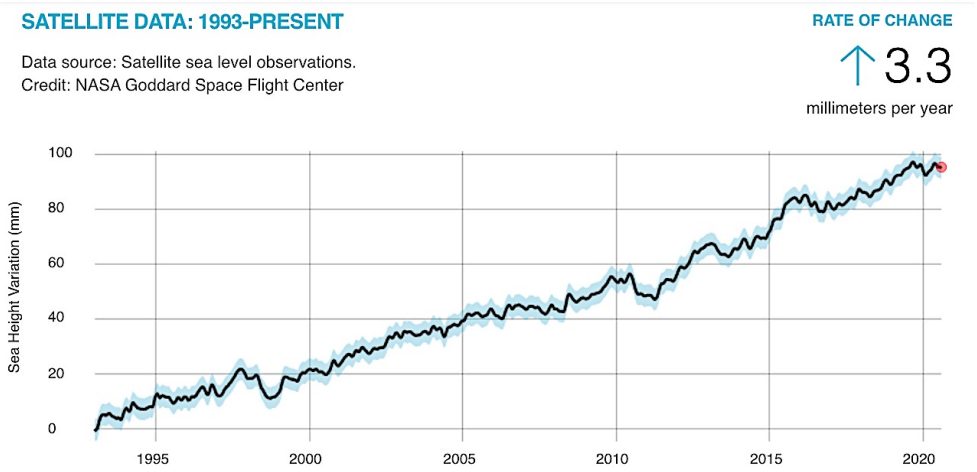


Figure 6.3.8: Sea height variation (mm) over time. Sea height has increased about 3.3 millimeters per year on average since 1993. Data is from satellite sea level observations by the NASA Goddard Space Flight Center. Image by NASA (public domain)

Projections for sea level rise to the end of this century vary widely. This is in large part because we do not know which of the above climate change scenarios (Figure 6.3.3) we will most closely follow, but many are in the range from 0.5 m to 2.0 m. One of the problems in predicting sea level rise is that we do not have a strong understanding of how large ice sheets, such as Greenland and Antarctica, will respond to future warming. Another issue is that the oceans do not respond immediately to warming. For example, with the current amount of warming, we are already committed to a future sea level rise of between 1.3 m and 1.9 m, even if we could stop climate change today.

? Optional Activity 6.3.2

What are the major causes of sea level rise?

A. Melting sea ice
B. Melting glaciers and ice sheets
C. Seawater expanding as it gets warmer
D. A and B
E. B and C

Answer

B and C. Melting glaciers and ice sheets and seawater expanding as it gets warmer.

Ocean Acidification and Deoxygenation

Since 1750, the ocean has absorbed about 30% of all anthropogenic carbon dioxide sources. When carbon dioxide gets absorbed in the ocean, it creates carbonic acid which makes the ocean more acidic. **Ocean acidification** is the process of ocean waters' decreasing pH (lower values are more acidic on the pH scale). 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. Most tropical oceans have experienced extensive coral bleaching events in recent years due to increased sea surface temperatures and ocean acidification. Ocean acidification also disturbs predator-prey dynamics by impairing the senses of prey species and compromising the ability of marine creatures to communicate with those within their same species.

Marine fish and invertebrates rely on dissolved oxygen that enters the water either through the atmosphere or by photosynthetic plankton. But because warmer water absorbs less oxygen, scientists predict that some areas of the ocean will see a 3–6% drop in dissolved oxygen concentrations under climate change. This process, known as **ocean deoxygenation**, will leave parts of the ocean unsuitable for marine fishes and invertebrates, leading to dead zones. The impact of ocean deoxygenation will also be felt by economically important fisheries where climate change is predicted to lead to fisheries-related economic losses upwards of $415 million each year.

Acidification combined with warmer temperatures and lower oxygen levels is expected to have severe impacts on marine ecosystems, especially coral reefs, and associated fisheries possibly affecting our ocean-derived food sources.

? Optional Activity 6.3.3

What causes ocean acidification?

A. Deoxygenated ocean water.
B. Ocean pollution.
C. Warm freshwater from land.
D. CO_2 dissolved in ocean water.

Answer

D. CO_2 dissolved in ocean water.

Climate Change Affects Everyone

We have all experienced the effects of climate change over the past decade. However, it is not straightforward for climatologists to make the connection between a warming climate and specific weather events, and most are justifiably reluctant to ascribe any

specific event to climate change. In this respect, the best measures of climate change are those that we can detect over several decades, such as the temperature changes shown in Figure 6.3.2, or the sea level rise shown in Figure 6.3.7.

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 is difficult to predict the exact impacts of climate change, what is clear is that the climate we are accustomed to is no longer a reliable guide for what to expect in the future.

It should be clear to anyone that climate change has the potential to greatly restructure the world's ecosystems, ecosystem services, and national economies. Many coastal areas will experience rising sea levels and increased flooding, while inland areas may experience desertification and less favorable crop-growing conditions. Those in developing countries will suffer the consequences disproportionately because of their limited mobility, high dependence on ecosystem services, and general lack of disaster management infrastructure.

If we are to mitigate the far-reaching impacts of climate change, we must carefully monitor and study changes in biological communities and ecosystem functioning, and how they relate to changes in climate and other stressors. While we may lose some species in a warmer world, we can also prevent many extinctions with proactive wildlife management. It is likely that many existing protected areas will no longer preserve some of the rare and threatened species that currently live in them, necessitating careful planning when establishing new protected areas. As goes nature, so goes humanity. Even if climate change is not as severe as predicted, the steps we take now to safeguard biodiversity, human health and safety, and economic stability can only help in the future.

Indigenous Connections: Climate Change Vulnerabilities

In 2019, the Tsleil-Waututh Nation published a report entitled, "Understanding Our Community's Climate Change Vulnerabilities: Community Climate Change Resilience Planning | PHASE 1 Summary". As noted in the report, "Climate change has the potential to profoundly impact the Tsleil-Waututh Nation (TWN) and many key aspects of community life. It influences the ability of our community to harvest some wild foods and medicinal plants, how we access the shoreline and marine waters, and how we connect with Nature. It poses community health risks, influence our ability to practice spiritual and cultural ceremonies, and share cultural teachings...This report serves to build an understanding of community vulnerability to climate change and begins to explore potential climate adaptation actions" (Tsleil-Waututh Nation, 2019).

The project focused on "climate change impacts to Tsleil-Waututh, also known as Burrard Inlet IR#3, which is the current village site for the Nation. In the future, TWN hopes to expand the assessment to consider the vulnerability of other areas within its traditional territory" (Tsleil-Waututh Nation, 2019).

Below is a summary of some of what this report details as possible impacts of climate change on the Tsleil-Waututh Nation:

- Coastal flood hazard modeling results showed that most waterfront properties may experience flooding during an extreme flood under a 2 m sea level rise scenario.
- Coastal erosion may affect waterfront properties and natural habitats, and threaten buildings, archeological, and other cultural sites.
- Ocean acidification from climate change poses an acute threat to species (particularly shellfish) along the mudflats and beaches of Burrard Inlet IR#3.
- [Loss of intertidal areas] will have significant impacts on species that live in the intertidal zone (e.g., shellfish) or that forage for food in these areas (e.g., marine birds and salmon). Many of these species are critically important as sources of food for TWN community and cultural health and serve as important opportunities to share traditional teachings (Figure 6.3.9).
- The waters of Burrard Inlet will be increasingly vulnerable to harmful algal blooms as water temperatures rise and summer precipitation decreases.
- Climate change has the potential to make local waters more habitable for invasive non-native species, particularly those from warmer waters.

- Extended periods of extreme heat can cause heat exhaustion or heat stroke, particularly among vulnerable groups.
- Community member health and the opportunity for recreation, cultural practices, and job productivity is also impacted by poor air quality and smoke from wildfires across BC.
- Ongoing changes to air temperatures and precipitation patterns from climate change could increase the success and abundance of some invasive species.



Figure 6.3.9: A keystone species, the ochre sea star (*Pisaster ochraceus*) taken at Ganges Harbour, Salt Spring Island, British Columbia, CC-BY-SA D. Gordon E. Robertson

Reference:

Tsleil-Waututh Nation. 2019. "Understanding Our Community's Climate Change Vulnerabilities: Community Climate Change Resilience Planning | PHASE 1 Summary" British Columbia, Canada. Available from: https://twnation.ca/wp-content/uploa...e-Jan-2020.pdf

Video



Learn how climate change will transform the planet with a 2oC rise in this 3-minute video.
Question after watching: Which of the changes will affect you directly? Which of the changes will affect you indirectly?

Video



Over the past few centuries, a handful of countries reaped the benefits of fossil fuels and developed their economies, emitting a lot of greenhouse gases along the way. But since the mid-2000s, an interesting shift has occurred. The majority of greenhouse gas emissions are now coming from large developing countries, who are looking for cheap energy sources to drive their own economic growth, just like rich countries before them.

Suggested Supplementary Reading

NASA. 2022. Global Climate Change: Vital Signs of the Planet. 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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6.4: Climate Strategies

Climate Strategies

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

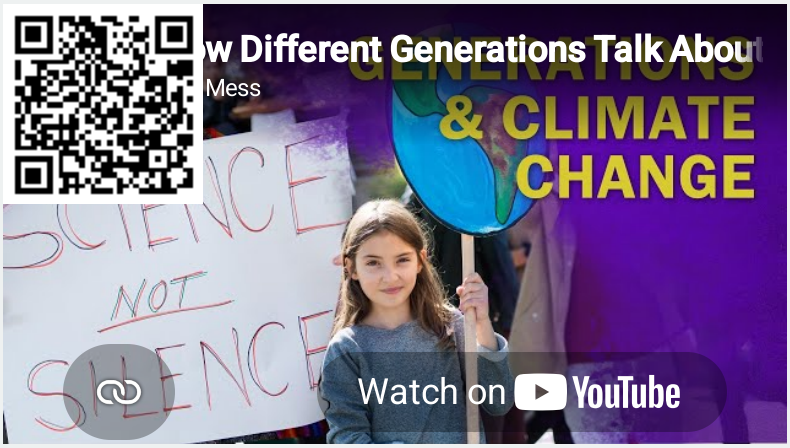
Learning Objectives

- Explain the global efforts to communicate about, and combat, climate change
- Describe the differences between adaptation and mitigation strategies

Introduction

With the increase in understanding that our activities are creating a global crisis of epic proportions, the impacts of climate change are now being actively debated in the corridors of governments and major corporations. Politicians, the media, and others are also increasingly replacing “climate change” with more vivid language, like “climate crisis” and “climate emergency.” This will hopefully encourage even more governments and industries to come to the table and cooperate like never before to address the fundamental drivers of climate change. Solving this global crisis requires an international multi-pronged approach that should include ecosystem protection, restoration, direct species management, reduction of carbon emissions, sustainable planning, and legislative action.

Video



What’s changed since the early days of the environmental movement? How are the stakes different today? And what’s the best way to speak up about climate change?

International Agreements

On the international front, key initiatives related to research and planning are being led by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), which in 1988 established the Intergovernmental Panel on Climate Change (IPCC). The IPCC undertakes comprehensive reviews of the science of global warming, with a focus on likely scenarios of climatic, ecological, and economic consequences. The IPCC also does research on ways to slow or prevent the increases in GHGs and on how economic and ecological systems might adapt to predicted climate change. At the international level, the IPCC is the most credible source of information about climate change.

Because of concerns about the potentially disastrous consequences of global warming, in 1990 the IPCC and other groups of climate specialists recommended that the United Nations (UN) mobilize global leadership to negotiate an international agreement to reduce emissions of GHGs. The UN then established an Intergovernmental Negotiating Committee to draft the terms of a **UN Framework Convention on Climate Change (UNFCCC)**. After a series of difficult international negotiations, the UNFCCC was drafted and then adopted in 1992 at the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil.

The objective of the UNFCCC is to stabilize atmospheric GHGs at concentrations that would prevent a dangerous intensification of the planetary greenhouse effect. Signatory nations to the UNFCCC, known as “parties to the convention,” have agreed to undertake certain actions to compile information on emissions of GHGs, develop policies to decrease emissions, prepare strategies to adapt to anticipated effects of climate change, and provide financial and scientific support to developing countries. Moreover, the 140 countries that signed the UNFCCC in Rio agreed to discuss its implementation at a global forum, which was held in Berlin in 1995. At that meeting, it was agreed that global emissions of GHGs should be reduced and a further series of international negotiations was needed to reach consensus on an implementation strategy. Those negotiations were completed at another meeting, held in Kyoto, Japan, in 1997. The outcome of that key meeting was the **Kyoto Protocol**.

Most years, since 1992, the world's countries have come together to renegotiate and discuss climate change at an UN-organized **Conference of the Parties** (Parties meaning those who signed to the UNFCCC), also known as "COP". As of 2022, COP27 was held in Egypt celebrating the 30th Anniversary of the ratification of the UNFCCC where attendees from 197 countries met to discuss solutions, financing, and collaboration.



Figure 6.4.1: Young people demand action to protect their futures at the 2021 UN Climate Change Conference, also known as COP26, held in Glasgow, Scotland. Photograph by UNFCCC, https://ukcop26.org/young-people-dem...ures-at-cop26/, Open Government Licence(OGL).

National and Local Action

The US never ratified the Kyoto Protocol, and, like most other developed countries, the US has not produced an effective strategy for meeting its legal obligations under agreements that followed, largely because of the intense political and economic controversies associated with the actions that would be necessary. Moreover, the government to date has focused on individual action and intensity-based targets, which encourage improved technological efficiencies but do not necessarily reduce the aggregate emissions of GHGs. Such tactics do little to reduce the rapid increase of emissions from increased industry and new fossil fuels coming online like the rapid expansion of natural gas in the last 30 years.

Climate policies have ebbed and flowed under the five presidential administrations since the Kyoto Protocol. During the Trump Administration (2017-2021), information regarding climate change and policies was removed from the internet. Under the Biden Administration, climate policies and agreements were reinstated and new short- and long-term strategies have been put forward. A primary goal is to reduce carbon emissions to 50-52% of 2005 levels by 2030. To achieve this, the following targets have been identified:

- Electricity: 100% carbon pollution-free electricity system by 2035 (backbone of the current climate policy)
- Transportation: 50% of all new light-duty cars to be zero emission by 2030; infrastructure to support all clean transportation (rail/tram, bike, pedestrian, etc.)
- Buildings: Improve energy efficiency and increase the sales share of clean and efficient electric appliances

- Industry: Focus on industrial decarbonization (energy efficiency, low-carbon fuels, industrial carbon capture and sequestration [see below])
- Agriculture, Forestry, and Land Use: Reduce agricultural methane and N_2O emissions; enhance forest protection and management; promote natural carbon sequestration forests and soils

Video



Popular support for climate action hasn't been translated into actual bold steps to reduce America's reliance on fossil fuels. So why is there this big discrepancy?

In addition, to combat climate change, the leadership of many states, counties, and cities have enacted laws and policies to reduce greenhouse gas emissions and habitat destruction in their own communities. Some industries are hard at work developing "greener" technologies to enable us to live more sustainably. Communities are coming together to implement solutions that are a best-fit for local environments and economies. Conservation biologists also play a crucial role in mitigating the negative impacts of climate change. In addition to highlighting the plight of the natural world to society at large, we could work towards reducing the loss of ecosystem services and preventing species extinctions. To accomplish this task, we need to identify which species and ecosystems are most sensitive to climate change and develop strategies that will ensure the continued persistence of as many sensitive species and their habitats as possible.

Video



Why is your local government so much better set up for implementing climate solutions than the federal government?

The situation surrounding global climate change is in serious need of our attention. It is important to realize that many scientists, leaders, and concerned citizens are making solutions to climate change part of their life's work (Figure 6.4.1). The two solutions to

the problems caused by climate change are mitigation and adaptation, and we will likely need a combination of both in order to prosper in the future.

Video



The UN's Sustainable Development Goals (SDGs) outline issues and strategies for the future of humans and natural systems. This 8.5-minute video describes SDG 13, which is focused on Climate Action.
Question after watching: Which of the strategies have you heard of before? Which strategies are new to you? What barriers to change resonate with you? What actions can you take to make change happen?

Climate Mitigation Strategies

In general, a strategy to mitigate climate change is one that reduces the amounts of greenhouse gases in the atmosphere or prevents additional emissions. Mitigation strategies attempt to “fix” the problems caused by climate change.

Greenhouse Gas Reduction

There are many options for reducing the adverse impacts to society from CO_2 and other greenhouse gas emissions, such as switching to sources of electricity that do not contribute to the CO_2 problem, trying to generate fossil-based electricity by not releasing the CO_2 into the atmosphere, or exploring ways to reduce the demand for products that produce greenhouse gas emissions. Governmental regulations regarding the fuel efficiency of vehicles is one example of an institutionalized mitigation strategy already in place in many countries around the world.

Putting a price on carbon is the method many economists favor for reducing or controlling greenhouse gas emissions. Pricing carbon provides producers and consumers with a monetary incentive to reduce greenhouse gas emissions by placing a value on each unit of carbon dioxide or carbon dioxide equivalent that is emitted into the atmosphere. The US currently does not have a carbon tax, even as it has been debated in the House and Senate for many legislative sessions. However, we can look to Canada for a system of **carbon taxes,** or charges for burning fossil fuels, to see how this might work to help society reduce greenhouse gases collectively.

Canada's "carbon pollution pricing system" has been in place since 2019. The federal pricing system has two parts: a regulatory charge on fossil fuels like gasoline and natural gas, known as the **Fuel Charge**, and a performance-based system for industries, known as the **Output-Based Pricing System**. Each province or territory can design its own pricing structure or the region will default to the Canadian government's minimum national stringency standards (known as the Federal Backstop) (Figure 6.4.2). Currently, this pricing mechanism is in place for the burning of fossil fuels such as gasoline or natural gas and for industries.

"Proceeds from the federal carbon pricing system remain in the jurisdiction where they were collected. Provinces and territories that requested the federal system receive these proceeds directly and can use them as they see fit. In other jurisdictions, the federal government delivers all proceeds to individuals, families, and businesses through payments and climate action programs. This helps make carbon pricing affordable, and enables households to make investments to increase energy efficiency and further reduce

emissions" (Government of Canada, 2022). This type of governmental mitigation strategy has been shown to be effective in many other countries including India, Japan, France, Costa Rica, Canada, and the United Kingdom.



Figure 6.4.2: The provinces and territories on the map of Canada are one of three colors depending on whether the federal backstop applies in full, in part or not at all. CC-BY-SA Government of Canada

Video



The average carbon footprint of a person in the US is 16.5 tons. So, what can you actually do to decrease this number and make a meaningful difference?

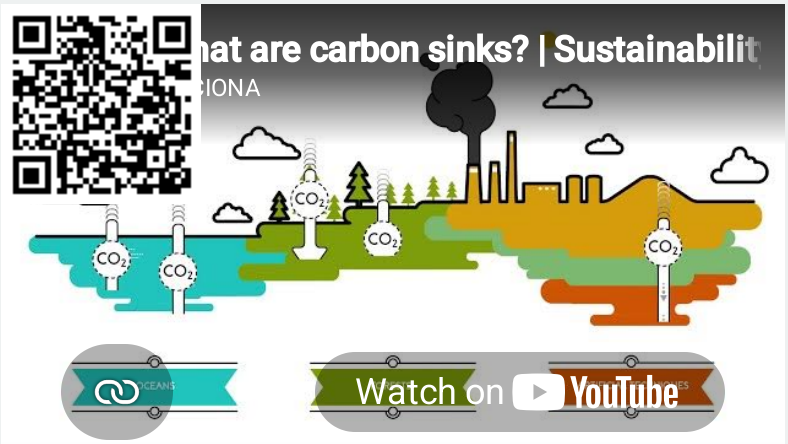
Carbon Capture and Sequestration

In addition to government measures and incentives, technology can also be harnessed to mitigate climate change. One strategy for this is the use of **carbon capture and sequestration** (CCS). Through CCS, 80-90% of the CO_2 that would have been emitted to the atmosphere from sources such as a coal-fired power plant is instead captured and then stored deep beneath the Earth's surface. The CO_2 is often injected and sequestered hundreds of miles underground into porous rock formations sealed below an impermeable layer, where it is stored permanently.

Scientists are also looking into the use of soils and vegetation for carbon storage potential. Proper management of soil and forest ecosystems has been shown to create additional carbon sinks for atmospheric carbon, reducing the overall atmospheric CO_2 burden. Increasing soil carbon further benefits communities by providing better-quality soil for agriculture and cultivation.

Technologies related to alternative energy sources mitigate climate change by providing people with energy not derived from the combustion of fossil fuels. Finally, simple activities such as energy conservation, choosing to walk or bike instead of driving, and disposing of waste properly are activities that, when done by large numbers of people, actively mitigate climate change by preventing carbon emissions.

Video



This 2-minute video describes using natural and artificial carbon sinks to help mitigate climate change but notes that these do not solve it.

Question after watching: What is the ultimate solution to mitigating climate change?

Climate Adaptation Strategies

Beyond mitigation, we know that climate change is already occurring as we can see and feel its effects. For this reason, it is essential to also adapt to our changing environment. This means that we must change our behaviors in response to the changing environment around us. Adaptation strategies will vary greatly by region, depending on the largest specific impacts in that area. For example, in the city of Delhi, India, a dramatic decrease in rainfall is projected over the next century. This city will likely need to implement policies and practices relating to the conservation of water like rainwater harvesting, water re-use, and increased irrigation efficiency. Rain-limited cities near oceans, such as Los Angeles, California may choose to use desalination to provide drinking water to their citizens. **Desalination** involves taking the salt out of seawater to make it potable. Cities with low elevations near oceans may need to implement adaptation strategies to rising sea levels, from seawalls and levees to relocation of citizens. One adaptation strategy gaining use is the creation or conservation of wetlands, which provide natural protection against storm surges and flooding.

The IPCC 6th Assessment Report (2022) outlines just some of the following global strategies for adaptation to climate change:

- Sustainable land use and urban planning
- Water use efficiency and water resource management
- Integrated coastal zone management
- Resilient power systems
- Health and health systems adaptation
- Planned relocation and resettlement
- Disaster risk management
- Climate services, including Early Warning Systems

Want to know more? Visit this site for short courses on Climate Change Adaptation Fundamentals: https://pcs.royalroads.ca/climate-change-adaptation-fundamentals-online

Indigenous Connections: Climate Action



In Canada, British Columbia's climate is changing, and Indigenous peoples are taking action to help their communities prepare and adapt to these impacts. In this 5-minute video, some actions are highlighted including helping the Klinse-Za caribou thrive in a new environment, adapting traditional food systems at T'eqt"aqutn'mux and Fort Nelson First Nation returning to fish camp.

Question after watching: Which of the adaptation measures listed above did you see in the video?

If we are to mitigate and adapt to the far-reaching impacts of climate change, we must carefully monitor and study changes in biological communities and ecosystem functioning, and how they relate to changes in climate and other stressors. While we may lose some species in a warmer world, we can also prevent many extinctions with proactive wildlife management. It is likely that many existing protected areas will no longer preserve some of the rare and threatened species that currently live in them, necessitating careful planning when establishing new protected areas. Even if climate change is not as severe as predicted, the steps we take now to safeguard biodiversity and our own future can only help.

Summary

1. While climate change is often thought of as a future challenge, we can already see its impacts today, as shown by record-high temperatures and changing rainfall patterns. These changes are happening because human activities release large amounts of greenhouse gases into the atmosphere on a daily basis.
2. Habitat loss contributes to climate change directly through the destruction of complex ecosystems (i.e. carbon sinks) which releases stored CO_2, and indirectly through the loss of vegetation that would otherwise sequester CO_2 from the atmosphere.
3. Some climatic shifts are predicted to be so rapid in the coming decades that many species will be unable to adjust their ranges to keep up with environmental changes. Species with dispersal limitations, special habitat requirements, and important mutualistic relationships are at an especially high risk of extinction.
4. Species are seldom exposed to only one threat; rather, different threats interact with climate change so that their combined impact is greater than their individual effects. A successful conservation strategy needs to deal with these threats collectively.
5. Mitigating the negative impacts of climate change will require an international multi-pronged approach that includes ecosystem protection and restoration, direct species management, and legislative action.

Optional Resources:

- US Global Change Research Program
- Individual actions (via EPA)
- UN's 2022 Conference of the Parties 27th Annual Meeting (COP 27)
- Intergovernmental Panel on Climate Change
- 10 Solutions to Climate Change (Scientific American)

Video



In the lead-up to the largest climate mobilization in history (the Climate March of 2014), this documentary weaves together the science, politics, and psychology of humanity's collective inaction to address the greatest ecological, social, and moral challenge of our time.

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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

8.1: The Impacts of Environmental Conditions

8.2: Impacts from Natural Determinants of Health

8.3: Environmental Toxicology

8.4: Bioremediation

8.5: Case Study - The Love Canal Disaster

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8.1: The Impacts of Environmental Conditions

Introduction to Environmental Health

When you think about the environment and health, what comes to mind?

Environmental health is one of the broadest topics in environmental sciences and environmental studies.

Watch the videos below and discover if the various topics included in environmental health were among those that you thought of based on the question above.

How the Environment Affects Your Health: Crash Course Public Health



There is no denying the effect that our environment has on us. Things like water and air pollution are detrimental to our health. In this episode of Crash Course Public Health, take a look at some of the ways our environment impacts us, why marginalized and low-income populations are disproportionately exposed to environmental pollution, and what can be done about it. [14 min]

How Does the Environment Affect Our Health?



Environmental health means paying attention to how the places we work, play, and live affect our health. Monitoring health threats, building better infrastructure, and involving the community in local decisions help ensure everyone's health and well-being. [5 min]

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8.2: Impacts from Natural Determinants of 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 disease and injury, both natural and anthropogenic, and taps resources within and outside public health and health care systems to improve health outcomes.

The natural environment impacts human health in many ways, but some of the most impactful and long-lasting effects stem from determinants rooted in unjust policies and socioeconomic systems (Table 1).

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.

How Society Affects Your Health



Society does a lot to improve our health, from sanitation to healthy foods. But society can also have negative effects on our health, and whether we experience positive or negative effects often depends on our social and economic standing.

Poverty, Health, and Environment

Global Health



Disease doesn't care about national borders. The pathogen hopping the red eye from Berlin to Boston doesn't need a passport. To be proactive in protecting our health, we need to think globally.

Environmental health risks can be grouped into two broad categories:

- **Traditional hazards** are associated with poverty and underdevelopment and primarily affect developing countries and those of lower socioeconomic status. These are most often women, children, those with disabilities/chronic illness, and other underrepresented minorities.
- **Modern hazards**, caused by technological development, prevail in industrialized countries where exposure to traditional hazards is low. In most developing countries, the contribution of modern environmental risks to the disease burden is similar to, and often greater than, that of developed countries. Urban air pollution, for example, is highest in parts of China, India, and some cities in Asia and Latin America.

Modern Hazards

Industrialized society releases vast amounts of pollutants and toxic waste into the biosphere, alters landscapes, and disrupts the global climate, resulting in a serious degradation of the Earth's ecosystems. The consequences of such actions eventually impact human populations' health and well-being.

- Air quality directly affects respiratory health, with exposure to pollutants such as ozone aggravating respiratory illnesses like asthma and COPD.
- Water quality is of paramount importance; contaminated water increases the risk of ingesting harmful chemicals, such as lead, and of contracting waterborne diseases.

- Food production and nutrition depend on the health of soil, water, and air.
- Food safety is also dependent on environmental health, as contamination during production, processing, and distribution can lead to outbreaks of foodborne illnesses such as salmonellosis.
- Waste management and sanitation systems are critical to protecting the environment and our health from contamination and diseases such as cholera.
- Climate change introduces another layer of complexity. More frequent extreme weather events, including extreme daytime and nighttime heat, significantly amplify risks. These events exacerbate respiratory and cardiovascular disorders and can lead to wildfires, which further degrade air quality. Warmer temperatures expand the range of disease-carrying vectors, thereby increasing the prevalence of vector-borne diseases such as Lyme disease, caused by Lyme borreliosis carried by ticks and transmitted directly to humans. Environmental disasters can impact our mental health, leading to disorders such as anxiety, PTSD, and depression.

Inequities compound these issues, with vulnerable populations disproportionately bearing the burden of environmental hazards, driven by factors such as proximity to industrial sites.

Chemical Agents

In terms of modern hazards, **chemical agents** 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 as they move up the food chain). For example, mercury from polluted water can accumulate in swordfish to levels toxic to humans. When toxic heavy metals enter the body, they accumulate in tissues and may eventually cause illness 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.

Double-Burdens

In most areas of the world, the poor 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.

The impact of traditional hazards 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 the Middle East (Figure 8.2.1).

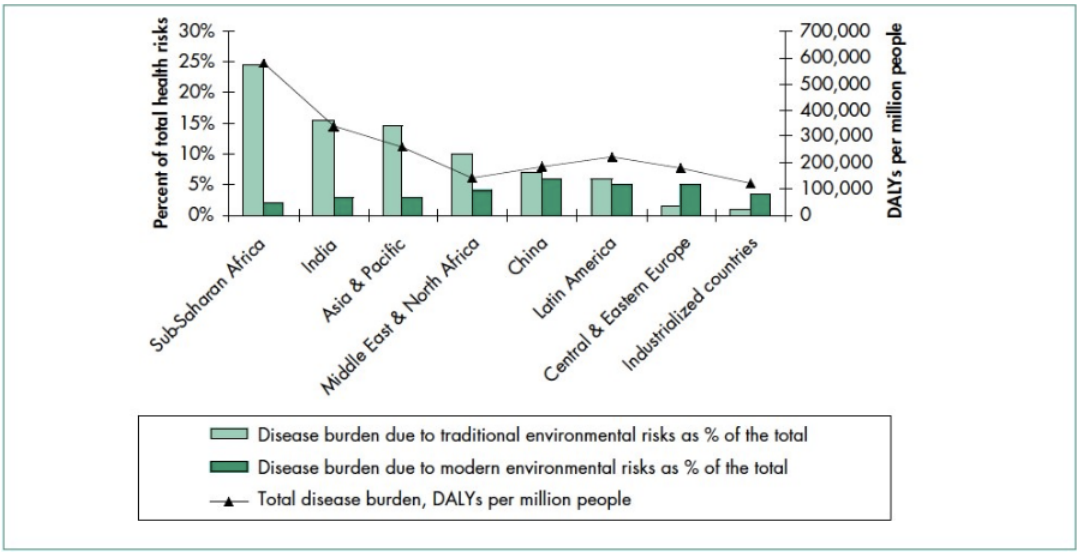


Figure 8.2.1. Traditional environmental health hazards prevail in developing countries, but modern risks are also significant.

Environmental Health, Women, and Children

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, and women who are pregnant or are of childbearing age are also at significant risk.

Double-Burdens

Around 2.1 billion people worldwide (around a quarter of the global population) cook using open fires or inefficient stoves fueled by kerosene, biomass (wood, animal dung, and crop waste), and coal, exposing people—mainly poor women and children—to high levels of indoor air pollution (IAP) (Figure 8.2.2).

Household air pollution was responsible for an estimated 2.9 million deaths per year in 2021, including over 309,000 deaths of children under the age of 5.& The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually.

Household air pollution exposure leads to noncommunicable diseases, including stroke, ischaemic heart disease, chronic obstructive pulmonary disease (COPD), and lung cancer.

Household air pollution accounted for an estimated 86 million healthy life years lost in 2019.

Women and children, particularly in low- and middle-income countries, are typically responsible for household chores such as cooking and collecting firewood, and bear the greatest health burden from the use of polluting fuels and technologies in homes.

Adapted from: World Health Organization. (2025, December 16). *Household air pollution*. World Health Organization Fact Sheets. https://www.who.int/news-room/fact-s...ion-and-health



Figure 8.2.2. A girl cooking inside over an open-fire stove. P4173887 Rob Goodier/Engineering for Change, CC-BY-SA 2.0

Malnutrition

Malnutrition (the condition that occurs when the 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.



Figure 8.2.3. Malnourished children in Niger, during the 2005 famine.

Poor Water and Sanitation Access

With 1.1 billion people lacking access to safe drinking water and 2.6 billion without adequate sanitation, the scale of these problems is significant. 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. 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.

Malaria

Malaria is an infectious disease spread by mosquitoes but caused by a single-celled parasite called *Plasmodium*, and one of the most impactful infectious diseases on Earth. Approximately 40% of the world's people—mostly those living in the world's poorest countries—are at risk from malaria. In 2024, there were an estimated 282 million cases and 610,000 deaths (mostly women and children), most in sub-Saharan Africa (most women and children). However, Asia, Latin America, the Middle East, and parts of Europe are also affected.

Pregnant women are especially at high risk of malaria. Pregnant women who are not immune to malaria risk both acute and severe clinical disease, resulting in up to 60% miscarriage and 10% maternal mortality. There is a 50% mortality rate for pregnant women with severe disease. Pregnant women who are semi-immune to malaria risk severe anemia and impaired fetal growth, even if they show no signs of acute clinical disease.

Malaria and the Environmental Consequences of DDT



Figure 8.2.4. DDT was a commonly used pesticide. *This work OpenStax, CC-BY 4.0.*

In addition to the diseases themselves, the measures to prevent them can sometimes also have environmental health consequences. For example, the insecticide DDT (dichlorodiphenyltrichloroethane) was widely used to control mosquito populations that transmit malaria in sub-tropical and 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.

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, this characteristic allows the chemical agent to biomagnify through the food chain. Populations of top-predator bird species, such as eagles and pelicans, are severely affected by DDT. 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. DDT is still produced in the United States and transported to Central and South America, where it is used on many crops, some of which are imported back into the US.

The Impacts of Emerging Diseases

Emerging and re-emerging diseases are 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 the magnitude of impacts. Examples include COVID-19, Ebola virus, West Nile virus, Zika virus, severe acute respiratory syndrome (SARS), H1N1 influenza, swine and avian influenza (swine flu, bird flu), HIV, and a variety of other viral, bacterial, and protozoal diseases. Click here for an up-to-date global health map from Harvard: https://healthmap.org/en/

Emerging Disease or Emerging Diagnosis?



Toward the end of the 20th century, deadly microbes seemed to be springing up out of nowhere: Lassa virus in 1969, Ebola virus in 1976, and HIV in the 1980s. Public health officials classified them as "emerging diseases," meaning they are newly introduced or rising rapidly in human populations. Recent data, however, suggest these viruses may instead have been circulating widely for hundreds or thousands of years. We may not be contending with an emerging disease at all, but an emerging diagnosis of an ancient and frequent disease. This paradigm shift has implications for countering these viruses now before they become global threats.

A variety of environmental factors may contribute to the re-emergence of a particular disease, including temperature, moisture, and sources of human or animal food. Disease re-emergence may result from the coincidence of several environmental and/or social factors that create optimal conditions for disease transmission.

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 diseases due to close human proximity and the likelihood that humans will be in “the wrong place at the right time” for disease to occur (e.g., 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 have been used for the past 80 years to treat patients with bacterial infections. **Note:** Antibiotics do not work to treat infections caused by viruses or fungi!

Since the 1940s, antibiotics have greatly reduced illness and death from these diseases and have been considered a miracle drug. However, for a number of factors, the infectious organisms the antibiotics are designed to kill have adapted to those medications, making the drugs less effective.

Antibiotic resistance occurs when bacteria change in ways that reduce 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 8.2.5). Antibiotic-resistant bacteria survive and continue to multiply, causing further harm.

New forms of antibiotic resistance can cross international boundaries and spread between continents with ease. Many forms of resistance spread incredibly fast. Each year in the United States, at least 2 million people acquire serious infections caused by bacteria resistant to one or more antibiotics designed to treat them. 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 driving antibiotic resistance worldwide.

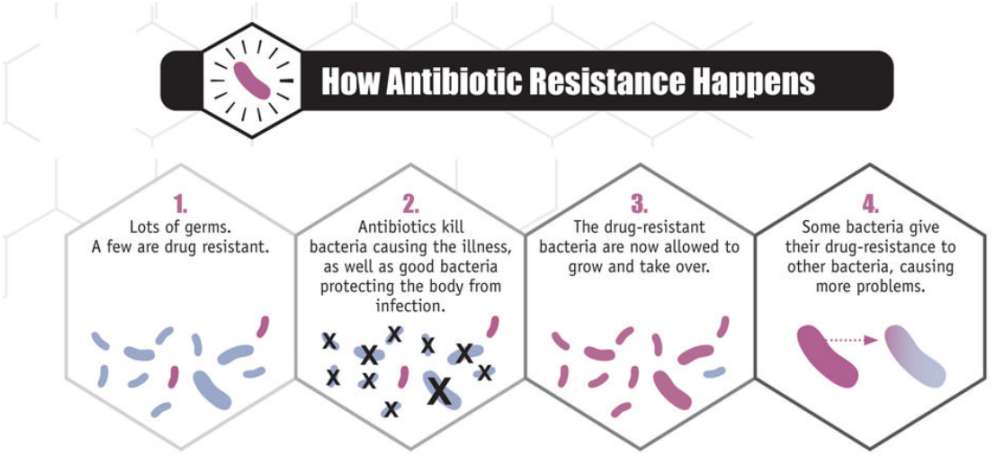


Figure 8.2.5. Antibiotic resistance is a growing concern for medical professionals.

The Evolution of Bacteria on a "Mega-Plate"



Watch this famous experiment (the "Mega-Plate" experiment) conducted at Harvard Medical School, demonstrating that bacteria can adapt very quickly to conditions that should be deadly to them.

How Are Humans Responsible for Antibiotic Resistence?

Humans have largely caused the problem of antibiotic resistance through overuse and incorrect use:

- Individuals:
  - Self-prescribing antibiotics (available in many countries over the counter) or by pressuring a physician to prescribe them when an antibiotic is not needed. Antibiotics are among the most commonly prescribed drugs in human medicine, but up to 50% of those prescribed are unnecessary or not optimally effective.
  - Not taking the full course of a prescribed antibiotic (e.g., only taking 3 days of a 10-day prescription because you start to feel better).
- Healthcare workers:
  - Prescribing the wrong antibiotic for the type of bacterial infection.
  - Prescribing the improper dose for the infection.
- Society/Industry:
  - Wide use of antibiotics in the agricultural industry as a prophylaxis against infection. More than 50% of all antibiotics are given to livestock in the United States alone. Living and working near common livestock vector species is another frequent cause of antibiotic resistance.
  - Poor infection control and sanitation. In recent years, there has been growing concern about a strain of *Staphylococcus aureus* that has become methicillin-resistant, known as MRSA. Another is VRSA (vancomycin-resistant *Staphylococcus aureus*). In the community, most MRSA infections involve the skin and may cause mild-to-moderate recurring infections in otherwise healthy people. Individuals who are immunocompromised or more susceptible may experience significant infections. For those who acquire MRSA in medical facilities (known as a nosocomial infection), MRSA can cause life-threatening bloodstream infections, pneumonia, and surgical site infections. Nosocomial infections are the leading cause of antibiotic-resistant illness.
  - Fast global travel can spread infections quickly (also true for viral infections such as COVID-19, measles, and flu).
  - Reduced overall funding by governments and pharmaceutical companies for new antibiotic research.
  - Medications of poor quality with little regulatory oversight.

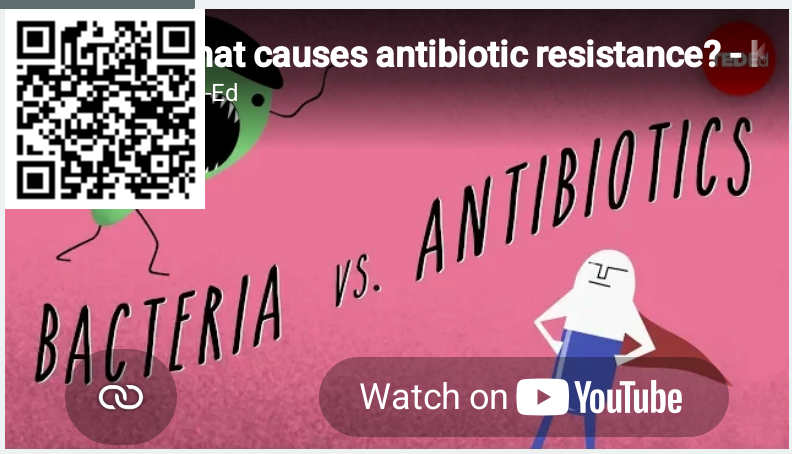
Additional Videos for Context

You are Mainly Microbe!



Ever not felt completely like yourself? There's a good reason for that. Because a large part of you . . . isn't you. Our bodies host ten times as many microbes as human cells. We are walking ecosystems, each of us home to thousands of different species on and inside of us. Meet your microbiome! Sure, some bacteria are dangerous, but without our tiny friends, we wouldn't be here (literally).

What Causes Antibiotic Resistance?



Explore how bacteria become resistant to antibiotics and turn into superbugs, and what scientists are doing to stop it.

How Can We Solve the Antibiotic Resistance Crisis?



Take a closer look at the challenges of antibiotic resistance and what we can do to prevent losing this vital medicine.

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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8.3: Environmental Toxicology

Introduction

Just because something is a chemical does not make it bad. After all, water is a chemical, air is a chemical, you are made of chemicals. The same goes for something that is labeled “natural” (which, by the way, has no legal definition). Arsenic, cyanide, and radiation are natural. None of those are good for you.

In this section, we will focus on environmental hazards. Some of these are natural, some contain natural ingredients, and some are produced entirely by humans. The toxicological hazards described below are those to which humans can be exposed and are often used to change aspects of our environment.

Linking the Environment and Human Health

Environmental health profoundly influences human health through an intricate relationship and various pathways that shape the well-being of individuals and communities.

Industrialized society is irresponsible in its treatment of natural systems. The consequences of such actions eventually impact human populations’ health and well-being.

The health of our environment is a crucial aspect of our overall well-being. As awareness of environmental pollution grows, it is essential to develop methods for measuring pollutants in our environment.

Environmental Agents and Hazards

Environmental hazards and exposure are a growing concern, with factors such as temperature and pollution affecting the health of individuals and populations. Accurate information and risk management models are crucial for understanding and addressing environmental risks and empowering individuals and communities to take action.

Environmental agents are specific substances that can directly interact with, and potentially impact, the health of the environment and humans. Environmental agents can be categorized into biological, chemical, and physical. The sources of environmental agents are diverse, ranging from human activities to natural disasters and biological events.

- Physical agents include noise, temperature, vibrations, radiation, and lighting, originating from various sources, including the built environment (human-made structures and surroundings) and industry.
- Chemical agents, including heavy metals, pesticides, polychlorinated biphenyls (PCBs), chlorofluorocarbons (CFCs), endocrine-disrupting chemicals (EDCs), and sulfur dioxide

(SO2), are used in agriculture, industry, and in the burning of fossil fuels for transportation and electricity generation.

- Biological agents were the most significant environmental health hazard through much of human history and include molds, dust mites, cockroaches, pollen, bacteria, viruses, protozoa, parasitic worms, and pet dander, saliva, and waste.

Environmental hazards originate from environmental agents, including industrial emissions and human activities, and can adversely affect human and animal health.

Human activities are the primary drivers of environmental agents, and societal and lifestyle choices, including urbanization, economic activity, recreational pursuits, and food habits, play a role. The presence of these agents, or toxins, in the air, water, and land can have deleterious effects on human health across the lifespan.

Environmental agents can create environmental health hazards, or conditions that have the potential to cause harm to the environment and humans.

Environmental Hazards and Impacts on Health

Environmental agents can pose hazards by polluting the air we breathe, the water we drink, and the food we eat, affecting our quality of life and overall health. While some of these hazards, such as smoke emanating from stacks, are clearly visible, most are not.

For example, small plastic fragments such as microplastics (MPs) and nanoplastics (NPs) are ubiquitous pollutants in water, air, and soil. NPs are more hazardous due to their extremely small size (<1000 nm), which allows them to escape water treatment processes and float long distances in both air and water, contaminating fresh water, oceans, air, and food. Furthermore, their size enables them to penetrate living tissues and cells more easily.

These particles are generated for use in consumer products such as cosmetics, cleansers, and detergents (major sources) and through the degradation of plastics such as tires (Lai et al., 2022). Small plastic contaminants can transport pollutants, microorganisms, and pathogens on their surfaces, thereby amplifying their physiological and environmental effects. While understanding of the impact of small plastics on human health is only just beginning to emerge, toxicological studies indicate that NPs can cross the blood-brain, intestinal, and placental barriers.

What Makes Something Hazardous?

A hazardous substance is defined in federal government regulations as “one that may cause substantial personal injury or illness during reasonable handling or use, including possible ingestion by children.”

According to the Federal Hazardous Substances Act (FHSA), household products are hazardous if they contain substances that have one or more of the following hazardous properties:

- ***Corrosive*:** A product that can burn or destroy living tissue, such as skin or eyes, or by chemical action.
  - Examples: Drain cleaners, oven cleaners, and lye.
- ***Irritant:*** A product is an irritant if it is not corrosive and causes injury to the area of the body that it comes in contact with after immediate, prolonged, or repeated contact.
  - Examples: Toilet cleaners, chlorine bleach cleaners, and some pool chemicals.
- ***Strong Sensitizer:*** A product that can cause an allergic reaction upon repeated use of the same substance. Usually, this does not happen when a person first comes in contact with the product, but after a second exposure.
  - Examples: Dyes, oils, tars, rubber, soaps, cosmetics, perfume, insecticides, wood resins, plants, paints, plastics, glues, fiberglass, metals, and polishes.
- ***Flammable:*** Any substance, liquid, solid, or the contents of a self-pressurized container, like aerosol cans, that can be easily set on fire or ignited. Extremely flammable, flammable, and combustible are the three flammability categories based on testing.
  - Examples: Paint thinners, some solvents, adhesives, rubber cement, and hair spray.
- ***Toxic:*** A product is toxic if it can cause long-term effects like cancer, birth defects, or neurotoxicity (toxic to nerves).
  - Examples: Brake fluids, fungicides, insecticides, fertilizers, rat poison, and antifreeze.

Routes of Exposure to Chemicals

Any product is hazardous if it can cause personal injury or illness to humans. To cause health problems, chemicals must enter your body.

There are three main “routes of exposure,” or ways a hazard can get into your body.

- **Ingestion:** Eating or drinking hazardous substances or contaminated foods and water, and absorbing these substances through your gastrointestinal tract.
- **Inhalation:** Breathing in gases, vapors, and sprays that are absorbed through the lungs and enter the bloodstream.
- **Dermal (skin or eye contact):** Some hazardous products can be absorbed through the skin or your eyes and cause injuries.

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?

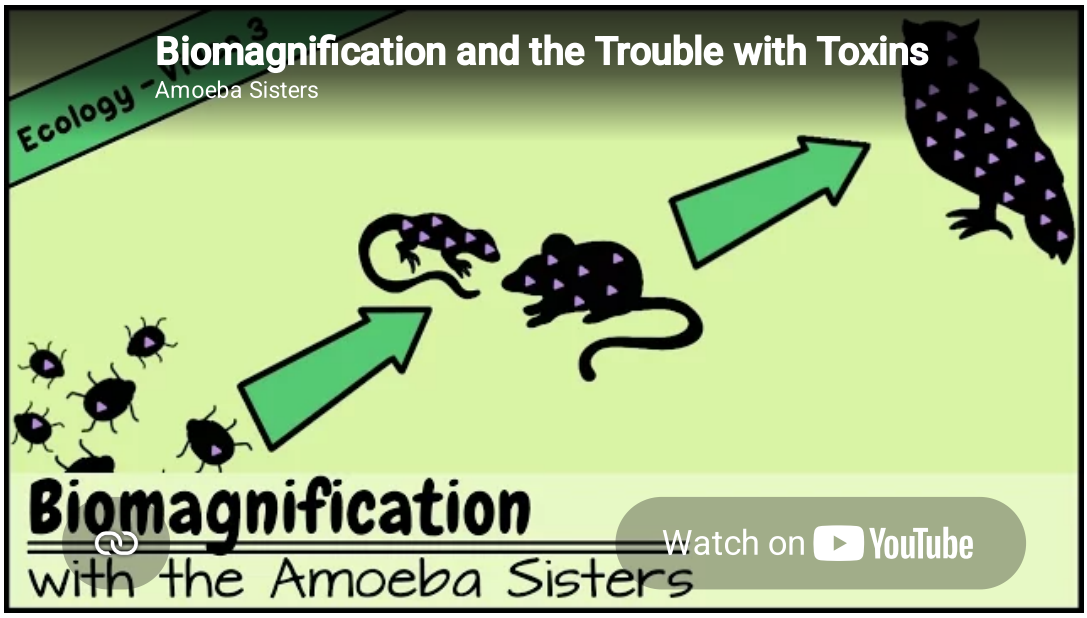
Chemical substances can take many forms. They can be in the form of solids, liquids, dusts, vapors, gases, fibers, mists, and fumes. The form a substance is in has a lot to do with how it gets into your body and what harm it can cause. A chemical can also change forms. For example, liquid solvents can 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 effects** are difficult to measure because they may not be apparent 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 to provide 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.





Contamination of air, water, or soil with potentially harmful substances can affect any person or community. Contaminants (Table 1) are often chemicals found in the environment in amounts higher than what would be there naturally.

Organisms 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 1. Classification of Environmental Contaminants

Contaminant	Definition
Carcinogen	An agent that may produce cancer (uncontrolled cell growth), either by itself or in conjunction with another substance. Examples include formaldehyde, asbestos, radon, vinyl chloride, alcohol, and tobacco.
Teratogen	A substance that 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, PFAS, and plasticizers such as bisphenol A (BPA).

An Overview of Some Common Contaminants

Arsenic is a naturally occurring element that is widely distributed in our environment, including water, soil, dust, air, and food. Levels of arsenic can regionally vary due to farming and industrial activity, as well as natural geological processes. Arsenic from farming and smelting tends to bind strongly to soil and is expected to remain near the land's surface for hundreds of years, providing a long-term source of exposure. Wood that has been treated with chromated

copper arsenate (CCA) is commonly found in decks and railings 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 enters the body through the ingestion of food or water. Arsenic in drinking water is a problem in many countries worldwide, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the United States. Arsenic may also be found in foods, including rice and some fish, 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 that 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 8.3.1 identifies the typical (average) amounts of mercury in commonly consumed commercial and sport-caught fish.

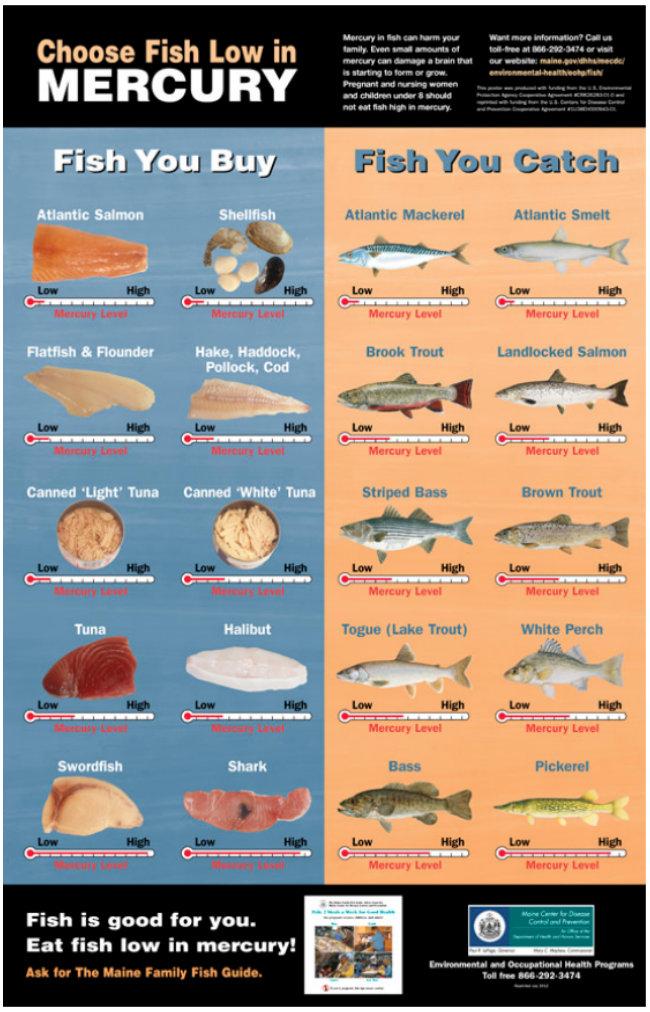


Figure 8.3.1. Mercury concentrations in fish can reach potentially dangerous levels (published by the *Maine Center for Disease Control & Prevention*).

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 on 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 BPA's effects. 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 overuse at high temperatures.
- Plastic containers have recycling codes on the bottom. Some, but not all, plastics marked with recycle codes 3 or 7 may contain 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 becomes softer and more flexible when phthalates are added. Phthalates are used in hundreds of consumer products. Phthalates are used in cosmetics and personal care products, including perfumes, hair sprays, soaps, shampoos, nail polishes, 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 containing phthalates or from breathing dust in rooms with vinyl miniblinds, wallpaper, or recently installed flooring that contains phthalates. We can be exposed to phthalates by drinking water contaminated with them. Phthalates are suspected to be endocrine disruptors.



Figure 8.3.2. 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, meaning it readily 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, carpets, and permanent press fabrics. Nail polish and commercially applied floor finish emit formaldehyde.

In general, indoor environments have consistently 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.

How Do You Know if a Household Product is Hazardous?

The FSHA requires that if a product contains a hazardous substance, it must bear a label of a specific size that contains certain information, depending on the product's toxicity.

“Signal Words” are found on every hazardous product label and indicate how toxic or hazardous a product could be (Table 2). If a signal word is not on a product, it is not hazardous.

Table 2. FSHA Signal Words for Household Products

Signal Words	Properties	Examples
POISON	highly toxic	varnish remover, antifreeze
DANGER	extremely flammable, corrosive, or highly toxic	bleach, WD-40
WARNING CAUTION	all other hazardous products	carpet cleaner, cleanser

Pesticides Have Additional Labeling

Pesticides are chemicals used to prevent, destroy, or repel pests, including insects, mice, weeds, fungi, and bacteria. Pesticides also include household products, such as disinfectants or cleaners, used to prevent the growth of harmful bacteria, viruses, or fungi on household surfaces.

The Environmental Protection Agency (EPA) registers and regulates pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). These products must meet the basic standards:

1. The product will not cause harmful effects to human health or the environment, and
2. Product labeling must meet FIFRA requirements. Examples: insecticides, rodenticides, herbicides, fungicides, microbial pesticides, etc.

Pesticides also have signal words, but they are based on the product's toxicity (Table 3). Tests are conducted to determine the Lethal Dose50 (LD50) of each pesticide.

LD50 is the dose at which 50% of a test population (usually mice or rats) dies when administered a specific dose of a pesticide. This is then calculated to a human dose.

The oral LD50 of a substance is expressed in milligrams of chemical per kilogram of body weight (mg/kg).

Table 3. FIFRA Signal Words and Toxicity Rating Scale for Pesticides

Signal Words	Toxicity	Oral LD50 (mg/kg)	Examples
DANGER-POISON	highly toxic	0 - 50	indoor/outdoor insect killer
DANGER	highly toxic/corrosive	0 - 50	toilet bowl cleaner
WARNING	moderately toxic	50 - 500	flea spray
CAUTION	slightly toxic	500 - 5,000	rat poison

Read Before You Use!

Besides signal words, product labels contain other important information, such as instructions for safe handling, use, and storage, active ingredients, and first aid safety.

As a consumer, make it a habit to read all label information before using any product.

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, such as 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.

Radon is a naturally occurring, colorless, odorless radioactive gas. It comes from the natural decay of uranium or thorium, which are 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 decays quickly, releasing 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.

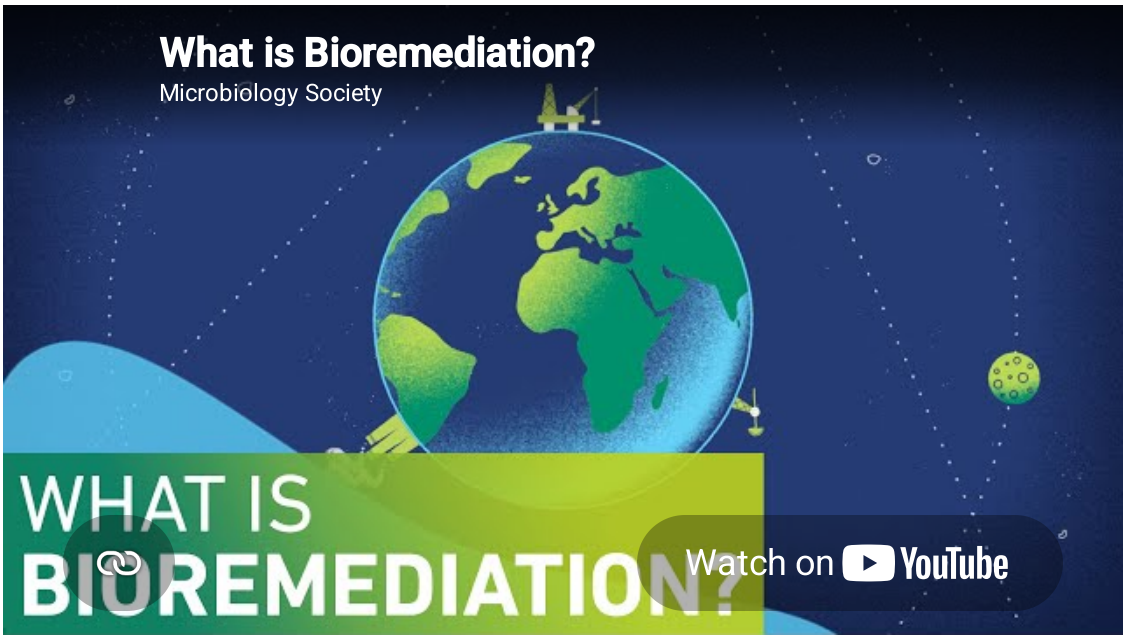
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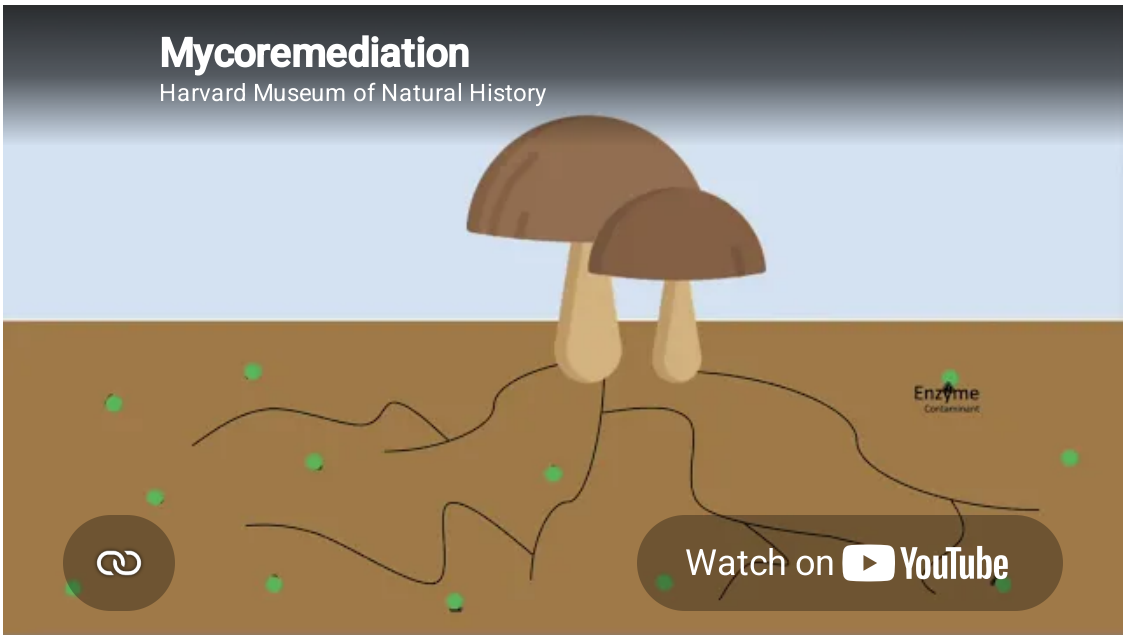
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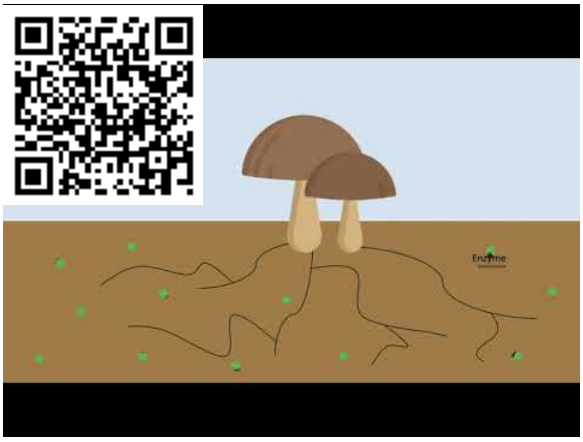
8.4: Bioremediation

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”.






Mycoremediation
Harvard Museum of Natural History
Enzyme
Watch on YouTube




The Plant That's Full Of Metal
MinuteEarth
Watch on YouTube



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 8.4.1), 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 8.4.1. (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-site treatment 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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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 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 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.

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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CHAPTER OVERVIEW

7: Biodiversity and HIPPPOC

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

Conservation biology is the management of nature and of Earth's biodiversity with the aim of protecting species, their habitats, and ecosystems from excessive rates of extinction and the erosion of biotic interactions. It is an interdisciplinary subject drawing on natural and social sciences and the practice of natural resource management.

Video



This 3-minute video summarizes Unit 7.
Question after watching: What areas from the video are you already familiar with? What topics are you unfamiliar with?

7.1: Introduction to Biodiversity
7.2: Importance of Biodiversity
7.3: The Biodiversity Crisis - HIPPPOC
7.4: Preserving Biodiversity

Image - The fruits of the forest canopy on Barro Colorado Island, Panama. Conservation Efforts Hinge on Understanding the Factors Controlling Biodiversity. (credit: Christian Ziegler CC BY 2.5)

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7.1: Introduction to Biodiversity

Introduction to Biodiversity

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Define biodiversity
- Explain what is meant by the 'biodiversity crisis'
- Provide examples of anthropogenic extinctions

Introduction

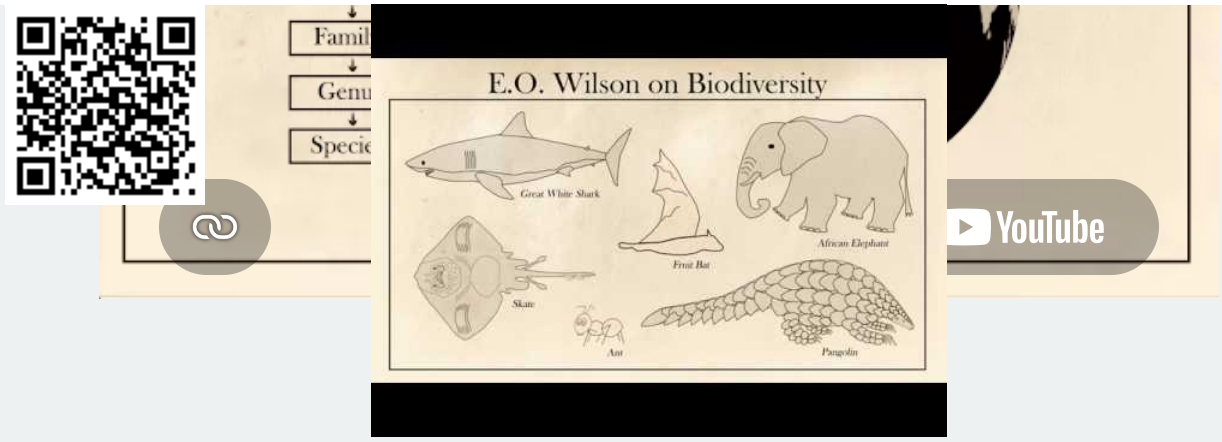
In the 1980s, biologists working in Lake Victoria in Africa discovered one of the most extraordinary products of evolution on the planet. Located in the Great Rift Valley, Lake Victoria (Figure 7.1.1) is a large lake about 68,900 km^2 in area (larger than Lake Huron, the second largest of North America's Great Lakes). Biologists were studying species of a family of fish called cichlids. They found that as they sampled for fish in different locations of the lake, they never stopped finding new species, and they identified nearly 500 evolved types of cichlids. But while studying these variations, they quickly discovered that the invasive Nile Perch was destroying the lake's cichlid population, bringing hundreds of cichlid species to extinction with devastating rapidity.



Figure 7.1.1: Cichlids are some of the most biodiverse fish on the planet but are also a casualty of devastating biodiversity loss. (credit: modification of work by Rishabh Tatiraju, using NASA World Wind software)

Video





Watch a 1-minute presentation by biologist E.O. Wilson (1929-2021) on the importance of biodiversity.

What is Biodiversity?

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.

Species Diversity

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 7.1.1). 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.

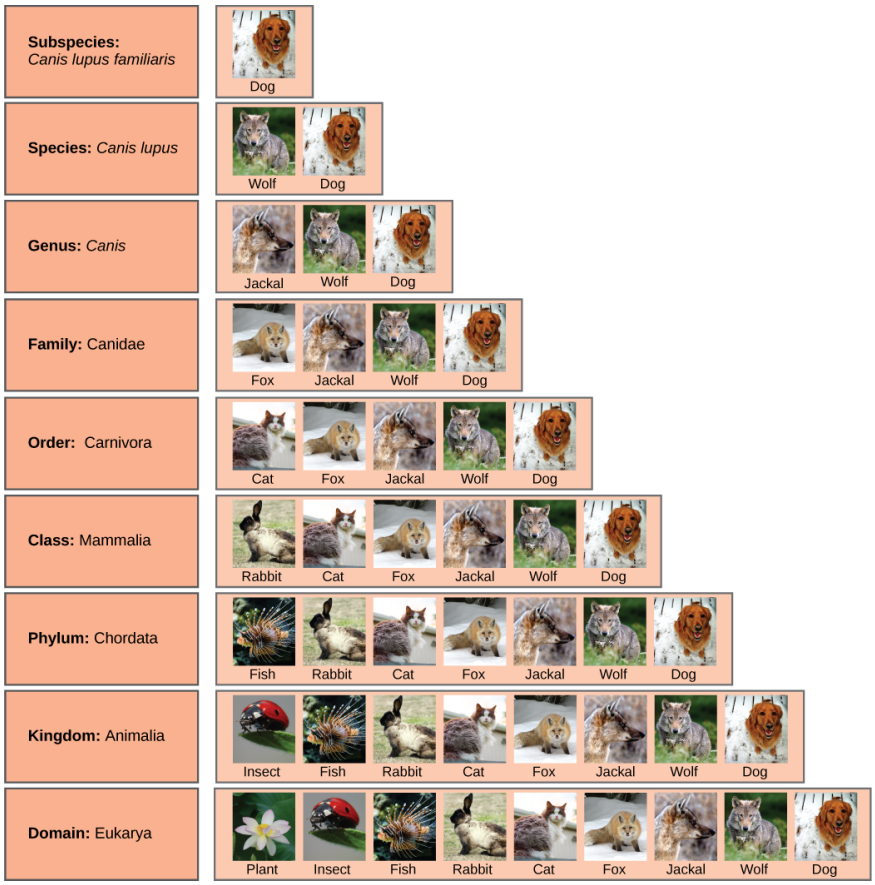


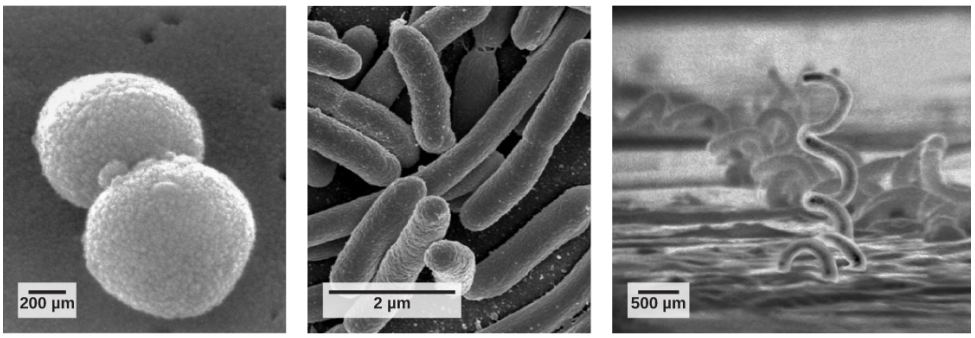
Figure 7.1.1. This illustration shows the taxonomic groups, in sequence, with examples. *This illustration by OpenStax is licensed under CC BY 4.0*

Domain Bacteria

Domain Bacteria includes prokaryotic, unicellular organisms (Figure 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.



(a) (b) (c)

Figure 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 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.

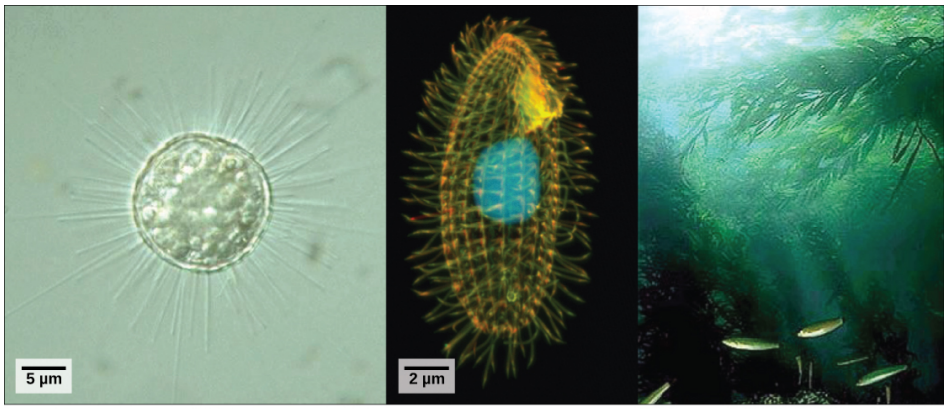


(a) (b) (c)

Figure 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 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 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*

Scientists accept that the term biodiversity generally describes the number and kinds of species in a location or on the planet. This is known as **species diversity**. Species can be difficult to define, but most biologists still feel comfortable with the concept and are able to identify and count eukaryotic species in most contexts.

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. An ecologist analyzing a forest with 10 equally common species of trees would note that this first forest is more diverse than a forest that has the same 10 species of trees but where just one of those species makes up 95 percent of the trees.

In addition to these measures of species diversity, biologists have identified alternate measures of biodiversity, some of which are important in planning how to preserve biodiversity.

Genetic Diversity

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. The same is true for higher taxonomic categories. A genus with very different types of species will have more genetic diversity than a genus with species that look alike and have similar ecologies. If there were a choice between one of these genera of species being preserved, the one with the greatest potential for subsequent evolution is the most genetically diverse one. It would be ideal not to have to make such choices, but increasingly this may be the norm.

Beyond ecological importance, genetic diversity has potential benefits for humans as sources of pharmaceuticals, so it provides one way to measure diversity that is important to human health and welfare. Humans have also generated diversity through domestic animals, plants, and fungi. This diversity is suffering losses because of migration, market forces, and increasing globalism in agriculture, especially in heavily populated regions such as China, India, and Indonesia. The human population directly depends on this diversity as a stable food source, and its decline is troubling biologists and agricultural scientists.

Ecosystem Diversity

It is also useful to define **ecosystem diversity**, meaning the number of different ecosystems on the planet or in a given geographic area (Figure 7.1.2). Whole ecosystems can disappear even if some of the species might survive by adapting to other ecosystems. The loss of an ecosystem means the loss of interactions between species, the loss of unique features of coadaptation, and the loss of biological productivity that an ecosystem is able to create. An example of a large, nearly extinct ecosystem in North America are the prairies (Figure 7.1.2*b*). 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 individual species survive but the hugely productive ecosystem as a whole has fallen apart. As a consequence, the most productive agricultural soils on the planet are disappearing or must be maintained at greater expense.



Figure 7.1.2: The variety of ecosystems on Earth—from (a) coral reef to (b) prairie—enables a great diversity of species to exist. (credit a: modification of work by Jim Maragos, USFWS; credit b: modification of work by Jim Minnerath, USFWS)

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 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.

How Many Species?

As of August 2025, taxonomists have described nearly 2.5 million species that share this planet with us. While this total may seem impressive, available evidence suggests that this estimate vastly underestimates the true extent of Earth's biodiversity. In fact, even now, after all the exploration in years gone by, several thousand new species are described each year. Many new discoveries are made by skilled researchers recognizing new species by discerning variation in morphological characters; that includes the discoveries of a new small forest antelope from West Africa and a new species of shark off the coast of Mozambique. New genetic technologies have highlighted that there are many thousands of species yet to be described. Both traditional and genetic techniques rely heavily on the availability of specimens in Natural History Museums' collections to help identify and describe new species. A lack of taxonomists and natural history collections in many of the world's most biodiverse countries means there is still a great deal of work to do.

The most exciting and newsworthy discoveries of new species generally involve higher-level taxa, especially living fossils. For example, in 1938, biologists across the world were stunned by the report of a strange fish caught in the Indian Ocean off South Africa. This fish, subsequently named *Latimeria chalumnae*, belongs to a group of marine fishes known as coelacanths that were common in ancient seas but were thought to have gone extinct 65 million years ago. Coelacanths are of interest to evolutionary biologists because they show certain features of muscles and bones in their fins that are comparable to the limbs of the first vertebrates that crawled onto land. Following the initial discovery, coelacanths have been found along Africa's Indian Ocean coast from South Africa to the Comoros and through to Kenya. Unfortunately, the entire coelacanth population, estimated at fewer than 500 individuals, is currently highly threatened because of ongoing fishing pressures.

Although field surveys have proven to be of great importance for discovering new species and populations, perhaps the greatest taxonomic progress has come from advances in genetic analyses, which help to separate cryptic species previously lumped under more widespread species. For example, advances in genetic research recently highlighted that the African clawed frog *Xenopus laevis*—a popular model organism in biomedical research—consists of seven distinct species.

Molecular genetics and data processing and storage technologies are maturing to the point where cataloging the planet's species in an accessible way is close to feasible. DNA barcoding is one molecular genetic method that takes advantage of rapid evolution in a mitochondrial gene present in eukaryotes, except for plants, to identify species using the sequence of portions of the gene. Plants are barcoded using a combination of chloroplast genes. Rapid mass sequencing machines make the molecular genetics portion of the work relatively inexpensive and quick. Computer resources store and make available large volumes of data. Projects are currently underway to use DNA barcoding to catalog museum specimens, which have already been named and studied, as well as testing the method on less studied groups. As of mid-2020, close to 750,000 named species had been barcoded. Early studies suggest there are significant numbers of undescribed species that looked too much like sibling species to previously be recognized as different. These can now be identified with DNA barcoding.

Numerous computer databases now provide information about named species and a framework for adding new species. However, at the present rate of description of new species, it would still take close to 500 years before the complete catalog of life is known. Many, perhaps most, species on the planet do not have that much time given the **anthropogenic**, or human-caused, pressures on species around the world (Unit 5.2.3).

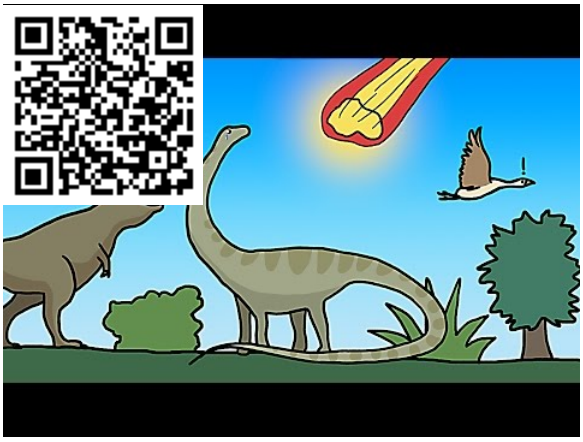
The presence of so many undiscovered species and communities makes precise estimates of species diversity incredibly difficult. Biologists' most recent estimates, combining genetic analysis of well-known groups with mathematical patterns, suggest there are 1 to 6 BILLION distinct species on Earth, of which there are only about 163 million animals and 340 thousand plants. This is obviously much greater than the current catalog of around 2.5 million species.

Anthropogenic Extinctions

There have been five previous mass extinctions on Earth. The sixth, or Holocene, mass extinction appears to have begun earlier than previously believed and is largely due to the activities of *Homo sapiens*.

Numerous recent extinctions of individual species have been recorded since the beginning of the Holocene period. Most of these coincide with the expansion of European colonies since the 1500s.





Recent Extinctions

These are only a few of the known and recorded extinctions in the past 500 years.

Dodo Bird

One of the earliest and popularly known examples is the dodo bird, which lived in the forests of Mauritius, an island in the Indian Ocean. Due to largely to overhunting for meat by sailors, as well as the introduction of non-native predatory species such as pigs, rats, and dogs, the dodo became extinct around 1662. The dodo had which did not evolve with predators, would approach these species and humans out of curiosity, making them easy prey (Figure 7.1.3).



Figure 7.1.3. The dodo bird was hunted to extinction around 1662. (credit: Ed Uthman, taken in Natural History Museum, London, England)

Steller's Sea Cow

Related to the manatee, the Stellar's sea cow probably once lived along the northwest coast of North America and was first discovered by Europeans in 1741. Hunted for meat and oil, it went extinct in 1768. That amounts to 27 years between the sea cow's first contact with Europeans and the species' extinction.

Passenger Pigeon

Once the most numerous bird in North America, they darkened entire stretches of sky during their migrations. Due to their numbers, they were hunted for food and fashion (feathers in women's hats, for example) and suffered habitat loss as farmlands expanded. In 1914, the last living passenger pigeon died in a zoo in Cincinnati, Ohio.

Carolina Parakeet

Once common in the eastern United States, the Carolina parakeet suffered from habitat loss through farmland expansion. As they adapted to the loss of their native food and began to eat orchard fruit instead, the species was hunted. In 1918, the last living Carolina parakeet died in captivity.

Japanese Sea Lion and Caribbean Monk Seal

The Japanese sea lion, which inhabited a broad area around Japan and the coast of Korea, became extinct in the 1950s due to hunting and conflicts with fishermen. The Caribbean monk seal, originally found throughout the Caribbean Sea, was hunted to extinction by 1952.

The Red List

There is also the problem of understanding which species known to science are currently threatened and to what degree they are threatened. The International Union for Conservation of Nature (IUCN), an international non-profit, keeps a list of extinct and endangered species called the Red List, supported by scientific research. The list is not complete, but it describes 47,000 species that are in danger of extinction. This is early 28% of all known species on the planet, including 44% of reef-building corals, 41% of amphibians, 38% of trees, 37% of sharks and rays, 34% of conifers, 26% of mammals, 26% of freshwater fishes, and 12% of birds.

Currently, the IUCN has assessed nearly 170,000 species, categorized by taxonomy and type of threat, with a goal of 260,000 by 2030.





Evolution Connection: Lake Victoria cichlids

The Lake Victoria cichlids provide an example through which we can begin to understand biodiversity. The biologists studying cichlids in the 1980s discovered hundreds of cichlid species representing a variety of specializations to particular habitat types and specific feeding strategies: eating plankton floating in the water, scraping and then eating algae from rocks, eating insect larvae from the bottom, and eating the eggs of other species of cichlid. The cichlids of Lake Victoria are the product of adaptive radiation. Adaptive radiation is a rapid (less than three million years in the case of the Lake Victoria cichlids) branching through speciation of a phylogenetic tree into many closely related species; typically, the species "radiate" into different habitats and niches. The Galápagos finches are an example of a modest adaptive radiation with 15 species. The cichlids of Lake Victoria are an example of a spectacular adaptive radiation that includes about 500 species.

At the time biologists were making this discovery, some species began to quickly disappear. A culprit in these declines was a species of large fish that was introduced to Lake Victoria by fisheries to feed the people living around the lake. The Nile perch was introduced in 1963, but lay low until the 1980s when its populations began to surge. The Nile perch population grew by consuming cichlids, driving species after species to the point of extinction (the disappearance of a species). In fact, there were several factors that played a role in the extinction of perhaps 200 cichlid species in Lake Victoria: the Nile perch, declining lake water quality due to agriculture and land clearing on the shores of Lake Victoria, and increased fishing pressure. Scientists had not even cataloged all of the species present—so many were lost that were never named. The diversity is now a shadow of what it once was.

The cichlids of Lake Victoria are a thumbnail sketch of contemporary rapid species loss that occurs all over Earth and is caused by human activity. Extinction is a natural process of macroevolution that occurs at the rate of about one out of 1 million species becoming extinct per year. The fossil record reveals that there have been five periods of mass extinction in history with much higher rates of species loss, and the rate of species loss today is comparable to those periods of mass extinction. However, there is a major difference between the previous mass extinctions and the current extinction we are experiencing: human activity. Specifically, three human activities have a major impact: the destruction of habitat, the introduction of exotic species, and over-harvesting. Predictions of species loss within the next century, a tiny amount of time on geological timescales, range from 10 percent to 50 percent. Extinctions on this scale have only happened five other times in the history of the planet, and they have been caused by cataclysmic events that changed the course of the history of life in each instance. Earth is now in one of those times.

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, biologists 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.

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 7.1.5). 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. 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 (Figure 7.1.5). Species–area estimates have led to estimates of present-day species extinction rates of about 1000 E/MSY and higher.

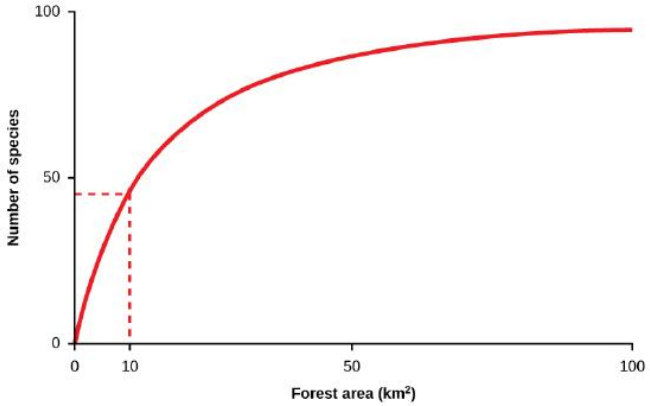


Figure 7.1.5. A typical species-area curve shows the cumulative number of species found as more and more area is sampled. The curve has also been interpreted to show the effect on species numbers of destroying habitat; a reduction in habitat of 90 percent from 100 km^2 to 10 km^2 reduces the number of species supported by about 50 percent.

Video



In this 9-minute video, discover why the current impacts of humans are as devastating to biodiversity as a large meteor.

Question after watching: What is lost when a species goes extinct? Consider all of the things that are lost, not just the biological ones.

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7.2: Importance of Biodiversity

Importance of Biodiversity

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 1 hour.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Summarize the benefits of biodiversity

Introduction

It may not be clear why biologists are concerned about biodiversity loss. When biodiversity loss is thought of as the extinction of the passenger pigeon, the dodo bird, and even the woolly mammoth, the loss may appear to be an emotional one. However, is the loss practically important for the welfare of the human species? The loss of a keystone species can lead to ecological disaster and the extinction of many other species. But, from the perspective of evolution and ecology, the loss of one or two individual species may be relatively unimportant. Extinction is a normal part of macroevolution. Humans have accelerated the extinction rate, though, leading to losses of tens of thousands of species within our lifetimes. These losses are likely to have dramatic effects on human welfare through the collapse of ecosystems and added costs to maintain food production, clean air and water, and human health. There are strategies to avoid some of these losses and the field of study to preserve biodiversity is known as **conservation biology**.

Video



Watch this 4-minute video for an understanding of the importance of biodiversity.
Question after watching: Humans have cut and frayed the woven tapestry of Earth's biodiversity. List and describe three ways.

The Biodiversity Crisis

Biologists estimate that species extinctions are currently 500–1,000 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 biologists have not yet discovered.

Most of these “invisible” species that will become extinct currently live in tropical rainforests like those of the Amazon basin or on coral reefs. Rainforests are the most diverse terrestrial ecosystems on the planet and are being destroyed rapidly by deforestation (Figure 7.2.1). Between 1970 and 2011, almost 20 percent of the Amazon rainforest was lost. Coral reefs are being lost to overharvesting, warming oceans, and pollution.



Figure 7.2.1. 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 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 as mentioned above, 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 many modern 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.

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. Some scientists estimate that there may be over 100 million species of prokaryotes alone. 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 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 with highly restricted distributions, like the ciclids, 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 (Unit 4.4.5). 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.

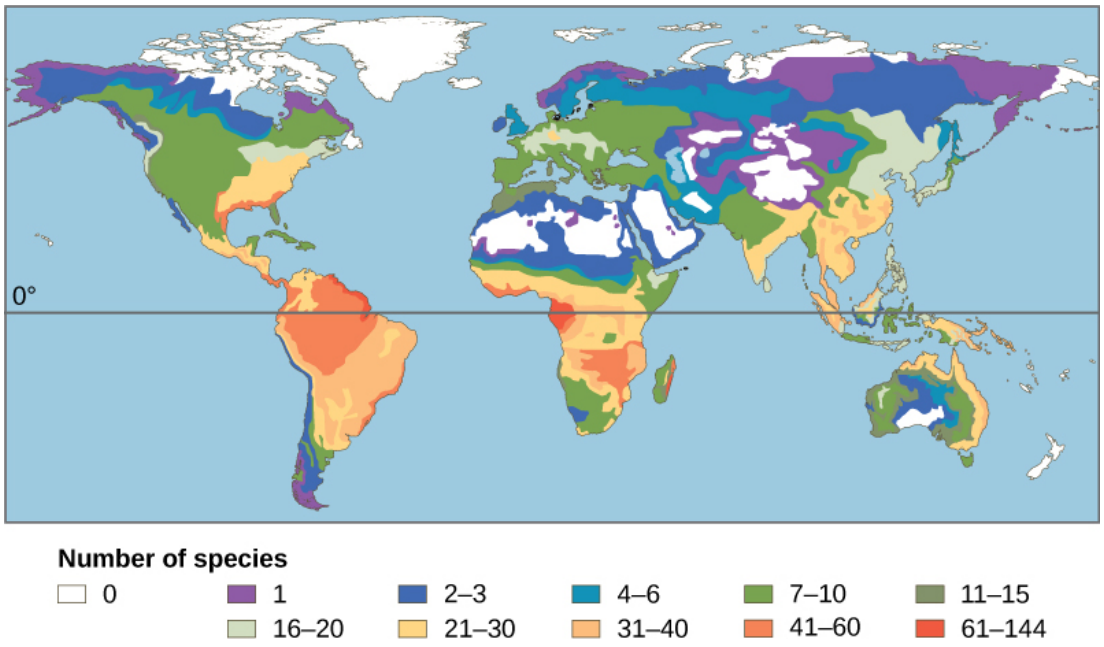


Figure 7.2.3. This map illustrates the number of amphibian species across the globe and shows the trend toward higher biodiversity at lower latitudes. A similar pattern is observed for most taxonomic groups.

One of the oldest observed patterns in ecology is that biodiversity typically increases as latitude decreases. In other words, biodiversity increases closer to the equator (Figure 7.2.3).

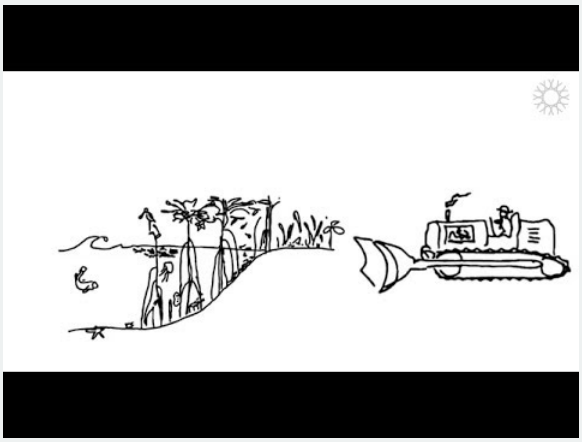
It is not yet clear why biodiversity increases closer to the equator, but hypotheses include the greater age of the ecosystems in the tropics versus temperate regions, which were largely devoid of life or drastically impoverished during the last ice age. The greater age provides more time for speciation, 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. Much of the importance of biodiversity comes from what is known as **ecosystem services** (Unit 5.2.3).

Video





In this 9-minute video by the California Academy of Sciences, the many ecosystem services that biodiversity provides are described.

Question after watching: Describe three different services and several examples of how biodiversity is important to humans.

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 as well as many other organisms such as elephants, bees, lizards, and canids 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 (from the white willow, *Salix alba*), codeine (from the poppy, *Papaver somniferum*), digoxin (from the genus *Digitalis)*, atropine (from the belladonna, *Atropa belladonna)*, and vincristine (Figure 7.2.4). 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 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 7.2.4. *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 more than 30% of pharmaceutical research and development is spent on natural compounds and that about 35% of new drugs brought to market between 1981 and 2002 were from natural compounds.

Agriculture

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 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 topography, 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 human-generated 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: the tragic Irish potato famine when the single variety grown in Ireland became susceptible to 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 the 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.

The ability to create new crop varieties relies on the diversity of varieties available and the accessibility 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 food supply.

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 banks are lost through accidents, and there is no way to replace them. In 2008, the Svalbard Global Seed Vault (Figure 7.2.5) 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. The seed vault is located deep into the rock of an 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 7.2.5. The Svalbard Global Seed Vault is a storage facility for seeds of Earth's diverse crops. (credit: Mari Tefre, Svalbard Global Seed Vault)

? Optional Activity 7.2.1

Figure 7.2.5: The Svalbard Global Seed Vault is located on Spitsbergen island in Norway, which has an arctic climate. Why might an arctic climate be good for seed storage?

Answer

The ground is permanently frozen so the seeds will keep even if the electricity fails.

Crop success is largely dependent on the quality of the soil. Although some agricultural soils are rendered sterile using controversial cultivation and chemical 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. If farmers had to maintain arable soil using alternate means, the cost of food would be much higher than it is now. 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. Over 150 crops in the United States require pollination to produce. One estimate of the benefit of honeybee pollination within the United States is $1.6 billion per year; other pollinators contribute up to $6.7 billion more.

Many honeybee populations are managed by apiarists 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, whose cause is unclear. 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; however, pesticides are costly and lose their effectiveness over time as pest populations adapt. They also lead to collateral damage by killing non-pest species and risking the health of consumers and agricultural workers. 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 on natural enemies of pests, the greater the complexity, the greater the effect of pest-suppressing organisms. An experimental study found that introducing multiple enemies of pea aphids (an important alfalfa pest) increased the yield of alfalfa significantly. This study shows the importance of landscape diversity via the question of whether a diversity of pests is more effective at control than one single pest; the results showed this to be the case. Loss of diversity in pest enemies will inevitably make it more difficult and costly to grow food.

Video



In this short 1.5-minute video, learn how biodiversity for food and agriculture is indispensable to food security, sustainable development, and the supply of many vital ecosystem services.
Question after watching: In what ways could you diversify your own diet and support local food growers?

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 a 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.

Psychological and Moral Value

Finally, it has been argued that humans benefit psychologically from living in a biodiverse world. The chief proponent of this idea was famed entomologist E. O. Wilson. He argued 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. In addition, there is a moral argument that humans have a responsibility to inflict as little harm as possible on other species.

Video



This 5.5-minute video from the EU's Science for Environment Policy summarizes many of the ecosystem services and benefits discussed above.

Question after watching: What is your opinion of using monetary values for nature to convince people to preserve or restore natural systems?

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The Biodiversity Crisis - HIPPPOC

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  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.

Learning Objectives

- Identify and explain the major causes of anthropogenic global change and their impacts on biodiversity.

Introduction

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, overexploitation (also known as overharvesting), pollution, predator losses, and introduction of invasive species. These are a direct result of human population growth, resource use, increased mobility, and trade (Unit 4.2.6). One of the major causes of extinction, **anthropogenic climate change**, is covered in more depth in the next section (Unit 5.3).

Together, these threats are known as **HIPPPOC**: **h**abitat loss, **i**nvasive species, **p**ollution, **p**opulation (human), **p**redator loss, **o**verexploitation, and **c**limate change.

Video

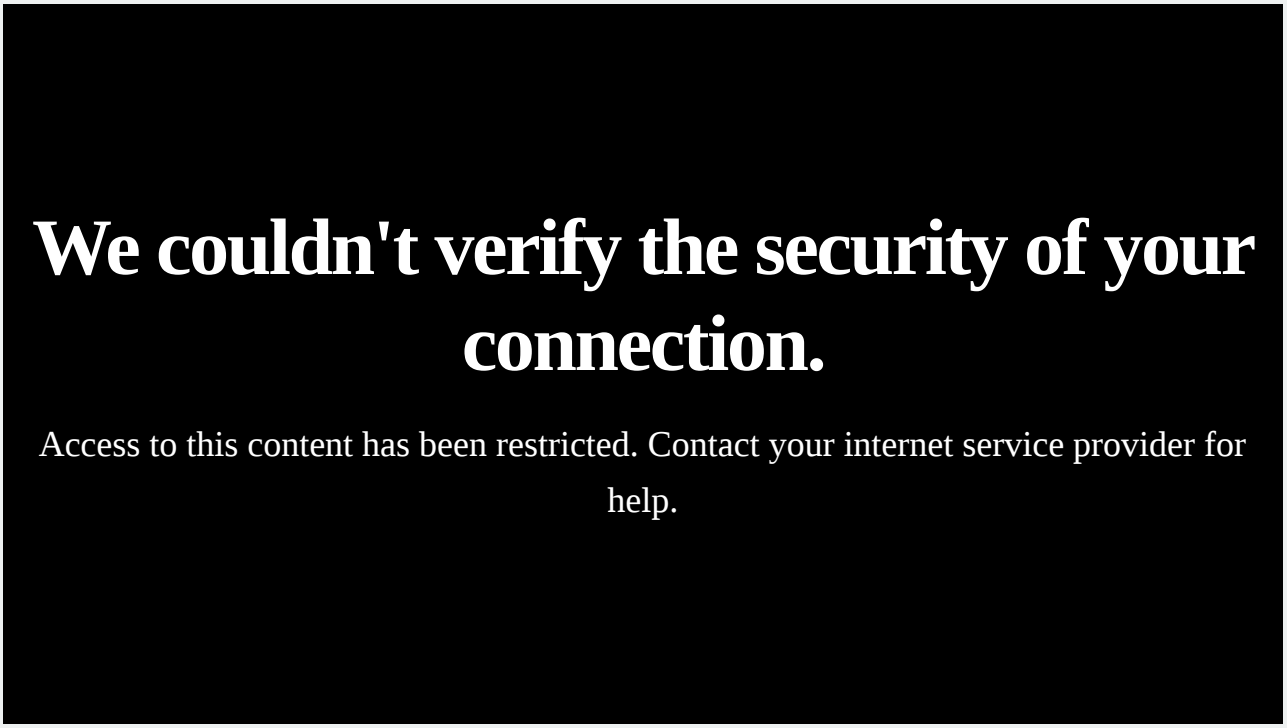


Half of the planet's wildlife (by number) has died off in the past 40 years.
Question after watching: Are we living in the 6th Mass Extinction? What is the evidence?

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 accelerated in the latter half of the twentieth century.

Video



Forests are essential habitats and carbon sinks. We are removing them at ever-increasing rates. Question after watching: Why is deforestation such a long-term problem?

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 7.3.1). 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.



(a)



(b)



(c)



(d)



(e)

Figure 7.3.1: (a) One species of orangutan, *Pongo pygmaeus*, is found only in the rainforests of Borneo, and the other species of orangutan (*Pongo abelii*) is found only in the rainforests of Sumatra. These animals are examples of the exceptional biodiversity of (c) the islands of Sumatra and Borneo. Other species include the (b) Sumatran tiger (*Panthera tigris sumatrae*) and the (d) Sumatran elephant (*Elephas maximus sumatranus*), both critically endangered species. Rainforest habitat is being removed to make way for (e) oil palm plantations such as this one in Borneo's Sabah Province. (credit a: modification of work by Thorsten Bachner; credit b: modification of work by Dick Mudde; credit c: modification of work by U.S. CIA World Factbook; credit d: modification of work by "Nonprofit Organizations"/Flickr; credit e: modification of work by Dr. Lian Pin Koh)

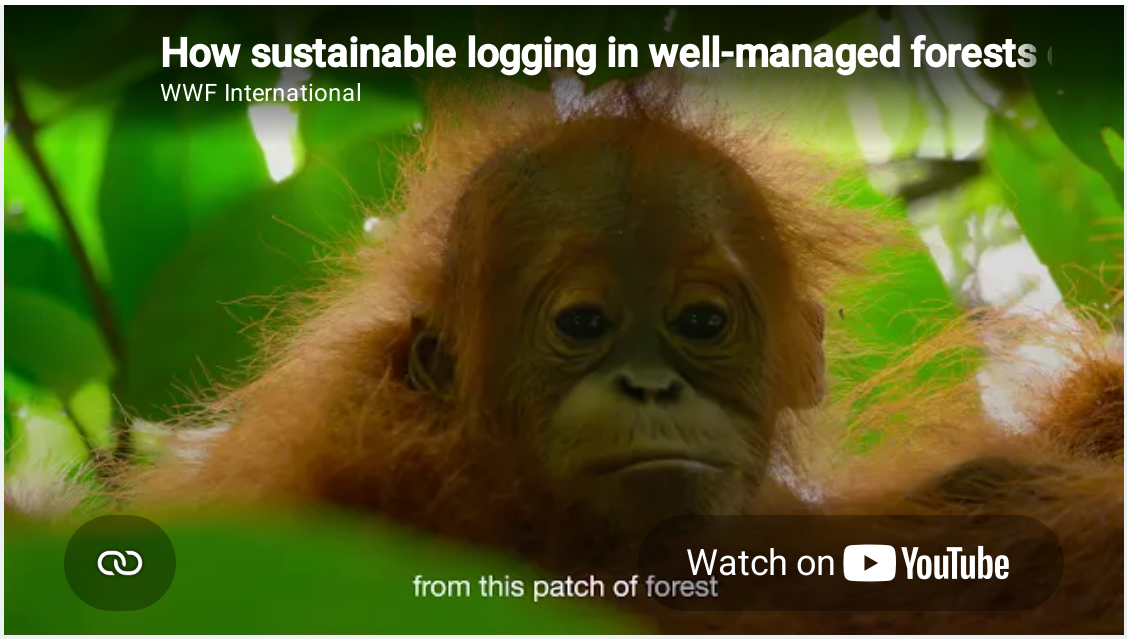
Preventing Habitat Destruction with Wise Wood Choices

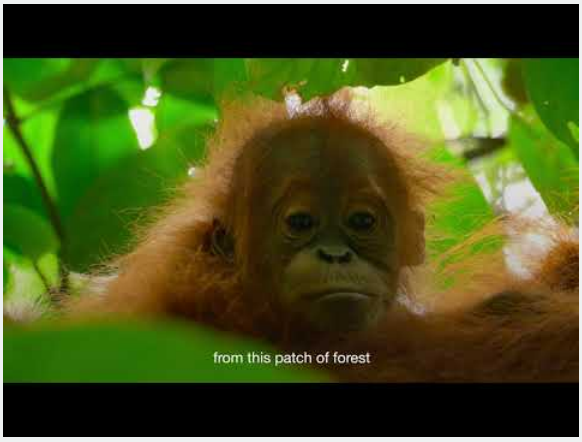
Most consumers do not imagine that the home improvement products they buy might be contributing to habitat loss and species extinctions. Yet the market for illegally harvested tropical timber is huge, and the wood products often find themselves in building supply stores. How is it possible to determine if a wood product, such as flooring, was harvested sustainably or even legally?

Various certifications can identify sustainably harvested forest products. Looking for certifications on flooring and other hardwood products is one way to ensure that the wood has not been taken illegally from a tropical forest. Some of these certifications are run by timber companies, however, 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. 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. Many fish species, including salmon, 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.





Foresters identify strategies to manage forest habitats sustainably by mimicking natural processes in this 3.5-minute video from the World Wildlife Fund.
Question after watching: What are benefits to sustainable logging as described in the video?

Invasive Species

Non-native species are those 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 often at distances that are well beyond the capacity of the species to ever travel on its own, and outside the range of the species' natural predators.

Most non-native 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 non-native species may undergo dramatic population increases in their new habitat and reset the ecological conditions in the new environment, threatening the native species that already exist there. When this happens, the non-native species is termed an **invasive species**. Invasive species can threaten other species through competition for resources, increased predation, or by causing new diseases.

Many invasive species are well suited evolutionarily to exploiting human transportation as a means to migrate, whether by air, sea, or land. The accidental introduction of the brown tree snake via aircraft (Figure 7.3.2) from the Solomon Islands to Guam in 1950 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. 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.

Lakes and islands are particularly vulnerable to extinction threats from non-native species. In Lake Victoria, the intentional introduction of the Nile perch was largely responsible for the extinction of about 200 species of cichlids. 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.

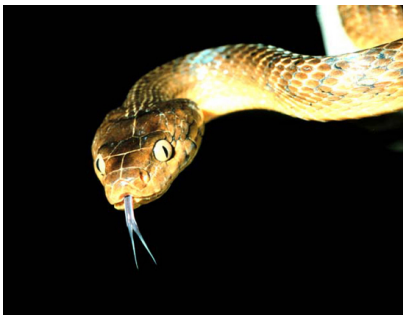


Figure 7.3.2. The brown tree snake, *Boiga irregularis*, is an exotic species that has caused numerous extinctions on the island of Guam since its accidental introduction in 1950. (credit: NPS)

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 7.3.3). 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 7.3.3. 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)

Video





In this 5-minute video, discover the devastating impact that invasive species can have on ecosystems. Question after watching: Do some research to find out what invasive species are a problem in your area? What is being done to combat them?

Pollution

Air 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**.

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.

A **point source** of air pollution refers to an emission source that does not move including factories, power plants, and dry cleaners. The term **non-point sources** is used to describe many sources of air pollution located together whose individual emissions may be

below thresholds of concern, but whose collective emissions can be significant. Non-point sources include the construction of housing developments, runoff from asphalt, and landfills. In crop production, the misapplication of fertilizers, herbicides, and pesticides can potentially result in aerial drift of these materials and harm may be caused.

Video



In this 4-minute video from National Geographic, learn how greenhouse gasses, smog, and toxic pollutants affect climate change and human health.

Question after watching: What strategies beyond those discussed in the video do you think will help to reduce air pollution?

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.

Water Pollution

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 7.3.4).



Figure 7.3.4. Water Pollution. Obvious water pollution in the form of floating debris, largely plastics; microscopic and chemical water pollutants are often much more harmful than visible ones. Source: Stephen Codrington at Wikimedia Commons

Water pollutants can move through different water reservoirs, as the water carrying them progresses through stages of the water cycle (Figure 7.3.5). **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.

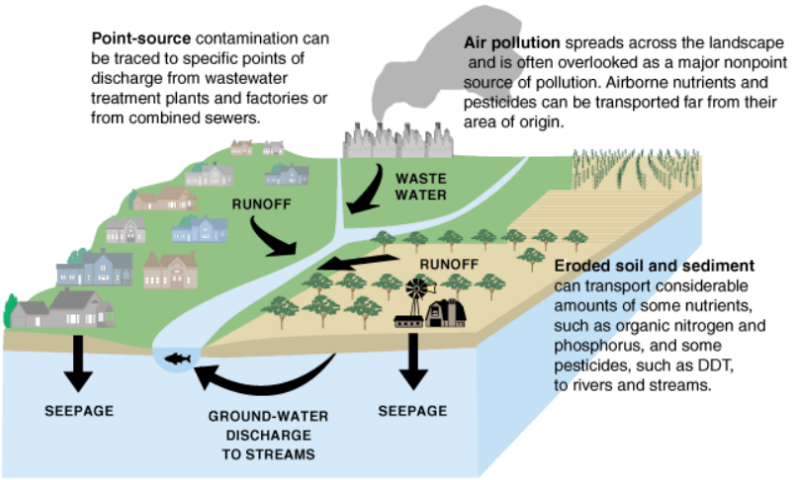


Figure 7.3.5. Sources of Water Contamination. Sources of some water pollutants and movement of pollutants into different water reservoirs of the water cycle. Source: U.S. Geological Survey

Like air pollution, water pollutants may enter the water cycle from point sources, which include identifiable and (generally) relatively small locations, or nonpoint sources, which include large and more diffuse areas. Point sources of pollution include animal factory farms (Figure 7.3.6) that raise a large number and high density of livestock such as cows, pigs, and chickens.



Figure 7.3.6. 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

Included in point sources are pipes from factories or sewage treatment plants. Combined sewer systems that have a single set of underground pipes to collect both sewage and stormwater runoff from streets for wastewater treatment can be major point sources of pollutants. During heavy rain, stormwater runoff may exceed sewer capacity, causing it to back up and spilling untreated sewage directly into surface waters (Figure 7.3.7).

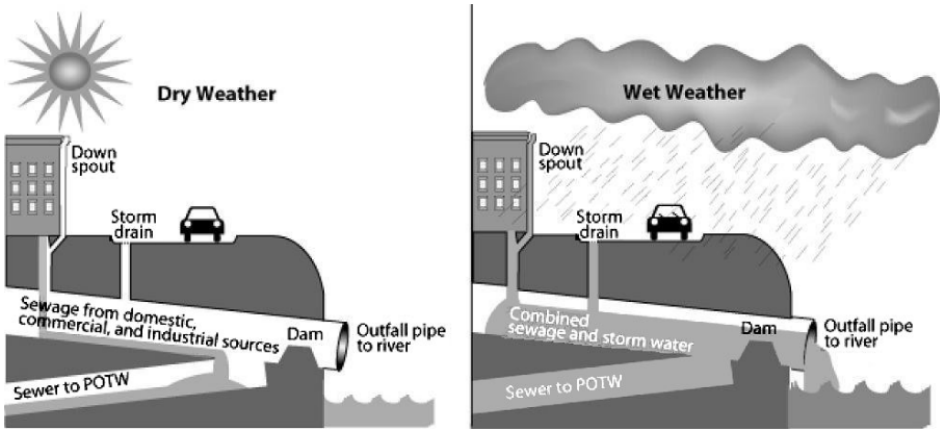


Figure 7.3.7. Combined Sewer System A combined sewer system is a possible major point source of water pollution during heavy rain due to overflow of untreated sewage. During dry weather (and small storms), all flows are handled by the publicly-owned treatment works. During large storms, the relief structure 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

Non-point 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. Non-point source pollution, which is the leading cause of water pollution, 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.

Video



In this 9-minute video, discover how the plastic we dump into the ocean might be hiding in plain sight. Question after watching: What is the ultimate solution to plastic waste in the ocean? What part can individuals play in this solution? What part can corporations play?

Population

As discussed in Unit 5, humans, while subject to the same ecological constraints as any other species (a need for nutrients, water, etc.), have some features as individuals and some as a population that make them a unique species. Unlike most other organisms, humans have the capacity to alter their number of offspring, level of resource consumption, and distribution. While most women around the world could potentially have the same number of children during their lives, the number they actually have is affected by many factors. Depending upon technological, cultural, economic and educational factors, people around the world have families of different sizes. Additionally, unlike other organisms, humans invent and alter technology, which allows them to change their environment. This ability makes it difficult to determine the human carrying capacity (Figure 7.3.8).

For example, families in developing nations are often larger, but less resource-intensive (e.g., they use fewer resources per person) than those in more developed nations. However, increasingly, human populations wish to have a developed-country standard of living. An increase in the world's average standard of living significantly lowers the potential human carrying capacity of the earth. Therefore, in order to reduce their impact as a species, humans must not only reduce the resources they use per person, but they must also reduce their average family size.

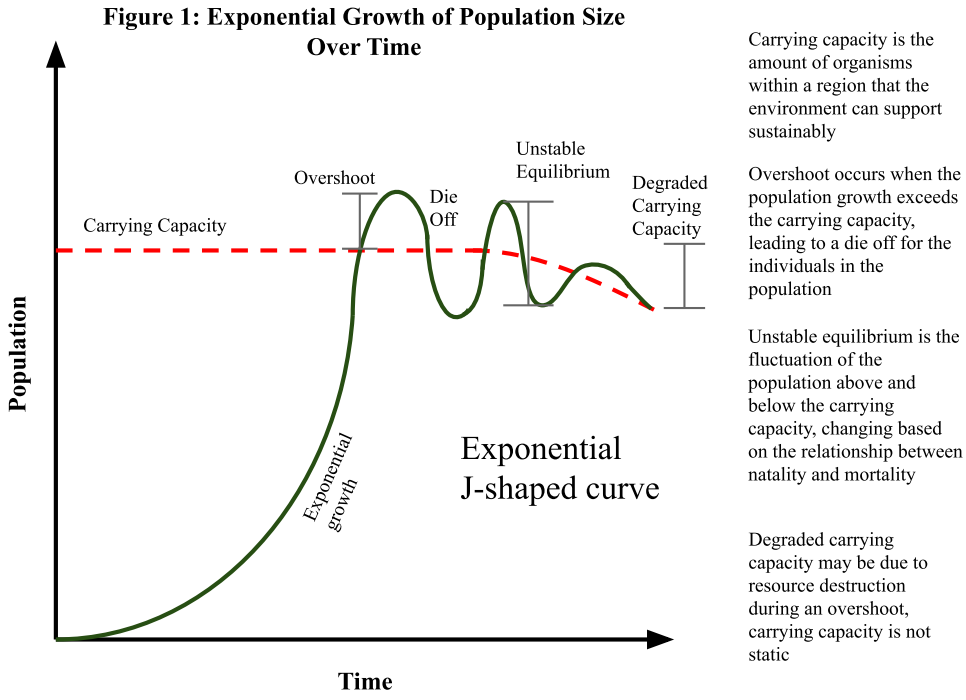


Figure 7.3.8: Reaching carrying capacity through exponential growth, followed by die-off and carrying capacity degradation (Copyright; Nchisick CC BY-SA 4.0)

Human Resource Utilization

Humans have always made an impact on the environment through their use of resources. For example, early humans were primarily hunter-gatherers who used tools to survive. They fashioned wood and stone tools for hunting and food preparation, and used fire for cooking. Early humans developed methods for changing habitats to suit their needs and herding wild animals. As time passed, humans developed more tools and techniques and came to rely on that technology in their daily lives. Although the tools of early humans were primitive by today's standards, they significantly affected the environment and probably hastened the extinction of some large Ice Age mammals.

Over the last 10,000 years, land clearing for agriculture has destroyed and degraded the habitats of many species of plants and animals. Today, growing populations in less developed countries are rapidly clearing tropical forests and savannas for agricultural use. These tropical rainforests and savannas provide habitat for most of the earth's species. It has become clear that modern agricultural practices are not sustainable. Once-fertile areas are becoming infertile because of overgrazing, erosion, and nutrient depletion. Furthermore, modern agriculture requires large inputs of energy and fertilizers, usually produced from nonrenewable fossil fuels.

Advanced industrialization leads to many changes in human society, and some of those changes negatively affect the supply of natural resources and result in environmental degradation. These changes include: increased production and consumption of goods by humans, dependence on non-renewable resources such as oil and coal, production of synthetic materials (which may be toxic or non-biodegradable), and consumption of large amounts of energy at home and work. For example, if everyone on the planet lived as the average person in the US, humanity would need the equivalent of 5.1 Earths to support everyone.

Other changes may have positive benefits. These include: creation and mass production of useful and affordable products, significant increases in the average gross national product per person, large increases in agricultural productivity, sharp rises in average life expectancy and a gradual decline in population growth rates. The information age was born with the invention of miniaturized electronics such as integrated circuits and computer central processing units. This stage in human development has changed and continues to change society as we know it. By making good use of information technologies, less developed countries may be able to reduce potential environmental problems as their economies expand in the future. With so much information easily

available, developing countries may not repeat the environmental mistakes that more developed countries made as they became industrialized.

Predator Losses

"The loss of apex consumers is arguably humankind's most pervasive influence on the natural world. This is true in part because it has occurred globally and in part because extinctions are by their very nature perpetual, whereas most other environmental impacts are potentially reversible on decadal to millenial time scales. Recent research suggests that the disappearance of these animals reverberates further than previously anticipated, with far-reaching effects on processes as diverse as the dynamics of disease; fire; carbon sequestration; invasive species; and biogeochemical exchanges among Earth's soil, water, and atmosphere."[1] The loss of these predators leads to what is known as **trophic cascades**.

"Predation is ubiquitous in nature and can be an important component of both ecological and evolutionary interactions. One of the most striking features of predators is how often they cause evolutionary diversification in natural systems. Predators are effective agents of natural selection because they possess key traits that allow them to capture and consume their prey; they adopt different strategies to do so, and they are common, but not too common, such that they can drive prey evolution without driving prey species to extinction."[2]

"Classic ecological studies that viewed predators as static entities that interact with prey in fixed ways resulting in predictable population dynamics are likely too simplistic. Today it is recognized that both predator and prey populations evolve—and that this evolution can happen very rapidly, even on ecological time scales, often with more than two species involved."[2]

"Ecosystems may be shaped by the loss of consumers. The loss of a single predator species may reverberate through the community. The loss of apex consumers reduces food chain length, thus altering the intensity of herbivory and the abundance and composition of plants in largely predictable ways. The transitions in ecosystems that characterize such changes are often abrupt, are sometimes difficult to reverse, and commonly lead to radically different patterns and pathways of energy and [matter]."[2]

Video



Scientists have discovered that reintroducing apex predators has led to successful recovery of previously damaged ecosystems, profiled in this 6-minute video from the IUCN.

Question after watching: Why do apex predators play such a crucial role in ecosystems and how can we effectively preserve them?

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.

Video



Learn about overfishing and its effects on ecosystems, food security, jobs, economies, and coastal cultures in this 4.5-minute video.

Question after watching: What can communities do to ensure their local waters are fished sustainably?

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 4,000 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 7.3.9.



Figure 7.3.9. 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*

Many around the world eat wild animals 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, wild meat in Africa was hunted to feed families directly. However, recent commercialization of the practice now has wild 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 wild meat trade are mostly mammals including many monkeys and the great apes living in the Congo basin.

Climate Change

Climate change, and specifically the anthropogenic (meaning, caused by humans) warming trend presently underway, is recognized as a major extinction threat, particularly when combined with other threats such as habitat loss. Extinction rate estimates range from 15 percent to 40 percent of species committed to extinction by 2050 due to climate change. 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 with their adapted climate norms while facing habitat gaps along the way.

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 (Figure 7.3.10). 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 species' delicate timing adaptations to seasonal food resources and breeding times. Many contemporary mismatches to shifts in resource availability and timing have already been documented.



Figure 7.3.10: Since 2008, grizzly bears (*Ursus arctos horribilis*) have been spotted farther north than their historic range, a possible consequence of climate change. As a result, grizzly bear habitat now overlaps polar bear (*Ursus maritimus*) habitat. The two kinds of bears, which are capable of mating and producing viable offspring, are considered separate species as historically they lived in different habitats and never met. However, in 2006 a hunter shot a wild grizzly-polar bear hybrid known as a grolar bear, the first wild hybrid ever found.

Range shifts are already being observed: for example, some European bird species ranges have moved 91 km northward. 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, 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 the only source of protein available to 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.

Finally, climate change will raise ocean levels due to meltwater from glaciers and the greater volume of 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 also be jeopardized. This could result in an overabundance of salt water and a shortage of fresh water.

More on climate change was in Unit 6.

Video



This 6-minute video from PBS discusses that as the world figures out how to live with a rapidly changing climate, traditional knowledge from indigenous cultures could help Western Science understand just how things are transforming.

Question after watching: In what ways is Indigenous Science dynamic regarding climate change? In what areas are Indigenous people facing discrimination in science?

Optional Activity 7.3.3

Converting a prairie to a farm field is an example of _____.

A. overharvesting
B. habitat loss
C. exotic species
D. climate change

Answer

B. habitat loss

Video



In this 3.5-minute video, learn of a 2019 United Nations report that says humans are transforming the planet's natural habitat at an unprecedented rate.

> *Question after watching: Are you optimistic or pessimistic of humans' capability to change and reduce their collective ecological footprint?*

Footnotes:

1. Estes, J.A. et al. 2011. Trophic Downgrading of Planet Earth. *Science.* 333(6040): 301-306: https://doi.org/10.1126/science.1205106

2. Johnson, J.B. and M.C. Belk. 2020. Predators as Agents of Selection and Diversification. *Diversity.* 12(11): 415; https://doi.org/10.3390/d12110415

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7.4: Preserving Biodiversity

Preserving Biodiversity

- Please read and watch the following Learning Resources
- Reading the material for understanding, and taking notes during videos, will take approximately 2 hours.
- Optional Activities are embedded.
- To navigate to the next section, use the Contents menu at the top of the page OR the right arrow on the side of the page.
  - If on a mobile device, use the Contents menu at the top of the page OR the links at the bottom of the page.



Introduction

Preserving biodiversity is an extraordinary challenge that must be met by a greater understanding of biodiversity itself, changes in human behavior and beliefs, and various preservation strategies. 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. A lofty goal is to protect 50% of the Earth's natural spaces for wildlife known as the Half-Earth Project, as described by the late Dr. E.O. Wilson below. Others, such as David Attenborough and Dr. Sylvia Earle, weigh in on the issue as well.

Videos





6-minute video with famed conservationist David Attenborough



6-minute video with famed biologist E.O. Wilson



3-minute video with famed marine biologist Sylvia Earle

Question after watching: What common themes do you find in the messages of these conservation ambassadors?

Changing Human Behavior

Ultimately, human behavior will change when human values change. At present, the growing urbanization of the human population is a force that poses challenges to the valuing of biodiversity. Legal avenues can help to protect biodiversity in the meantime.

International Legislation

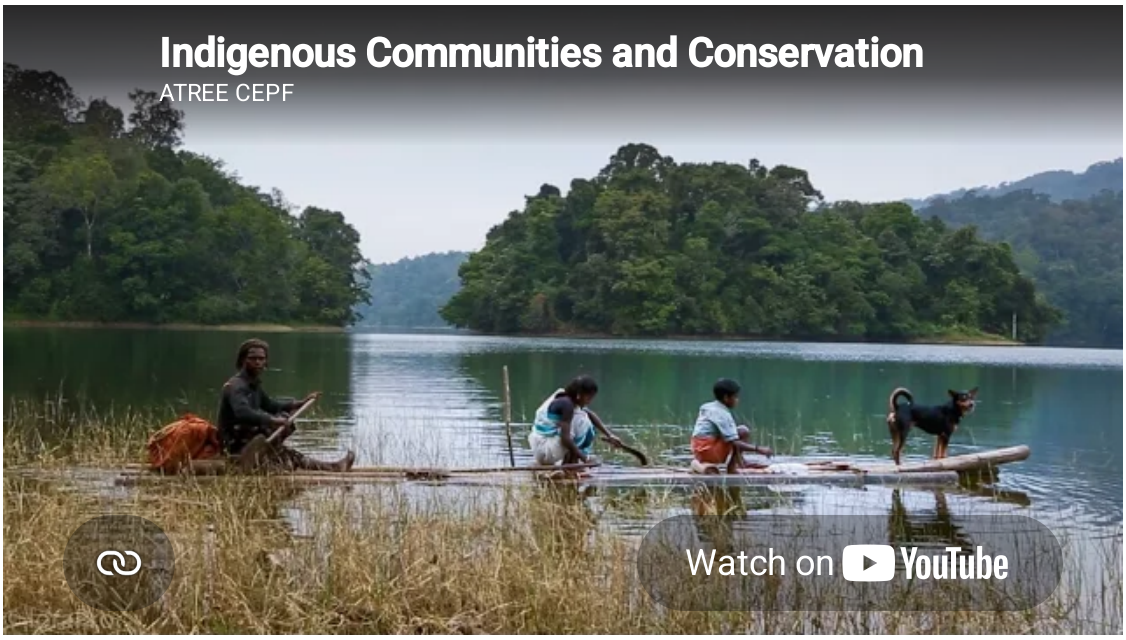
Legislation throughout the world has been enacted to protect species. The legislation includes international treaties as well as national and provincial laws. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (**CITES**) agreement came into force in 1975. The agreement, and the national legislation that supports it in Canada and most other countries, provides a legal framework for preventing approximately 33,000 listed species from being transported across national borders, thus protecting them from being caught or killed when international trade is involved. The treaty is limited in its reach because it only deals with the international movement of organisms or their parts. It is also limited by some 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. Illegal wildlife trade is monitored by a non-profit: Trade Records Analysis of Flora and Fauna in Commerce (**TRAFFIC**).

The **Convention on Biological Diversity** is now the leading international treaty to advance the conservation of biodiversity, within the context of a comprehensive agenda for sustainable development. The three key goals of the Convention are the conservation of biodiversity, the sustainable use of its components, and the equitable sharing of benefits from the use of genetic resources. The 194 ratified parties to the Convention are engaged in a multitude of cooperative initiatives and information and technology sharing, and are committed to identify and conserve their biodiversity.

A key action is to periodically undertake science assessments of the status of global biodiversity. Broadly speaking, the most recent assessment found that the prospects of biodiversity were rapidly worsening in many parts of the world, although considerable progress was being made in cooperative planning and in the designation of protected areas and other conservation measures in many countries. It is too soon to tell whether these international actions will be successful because the programs began only in the late 1970s (as an earlier program called the World Conservation Strategy). However, it is encouraging to know that this sort of comprehensive international effort exists and that almost all of Earth's nations are participating, including countries in all stages of economic development.

On an international level, important wilderness lands have been designated by the United Nations through its "**Man and the Biosphere Program**." This program was established in 1973 to protect examples of major natural regions throughout the world, and provide opportunities for ecological research and education.

Biosphere reserves are organized into three interrelated zones: the **core area**, the **buffer zone** and the **transition area**. The core area contains the landscape and ecosystems to be preserved. The buffer zone is an area where activities are controlled to protect the core area. The outer transition area contains a variety of agricultural activities, human settlements and other uses. Local communities, conservation agencies, scientists and private enterprises that have a stake in the management of the region work together to make the reserves work. Mt Kenya in Africa and the Galapagos Islands are examples of wilderness areas protected under this provision.





US Legislation

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.

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.

The ESA recognizes five categories of risk, each of which has a specific meaning in terms of imminent threats to the future survival of the species (COSEWIC, 2015).

- **Extinct** refers to any species of wildlife that was formerly indigenous to the US but no longer exists anywhere in the world.
- **Extirpated** refers to any species or subspecies that was formerly indigenous to the US but now only survives in the captivity or elsewhere, usually in Canada or Mexico.
- **Endangered** refers to native species that are faced with imminent extinction or extirpation throughout all or a significant portion of their range.

- **Threatened** refers to any indigenous taxon that is likely to become critically imperiled unless factors affecting its status are reversed.
- **Vulnerable** refers to any indigenous species that is not currently imperiled but is at risk of becoming so because of small or declining numbers, occurrence at the fringe of its range or in restricted areas, habitat fragmentation, or some other reason.

It must be recognized that the designation of species at risk is a continuing and always incomplete process. For instance, because the conservation status of only a few species of invertebrates has been investigated, critically imperiled species in this group are enormously under-represented in the ESA list. Unfortunately, more rapid progress is constrained by a shortage of funding for research and monitoring of endangered species, and by a lack of specialists with the necessary taxonomic and ecological skills and knowledge.

Of course, it is not sufficient merely to designate species as being at risk of extirpation or extinction. If their status is to be improved, the species and their habitats must also be protected. Remarkably, the US federal government has not yet enacted effective legislation to protect endangered species and their habitat across the whole of the country. However, this situation is starting to change.

However, federal legislation has little direct influence on the status of the many threatened and vulnerable that are living on state, private, or Indigenous land. Most importantly, the Act does not fully address the protection of habitat of critically imperiled species off federal land. To some degree, this deficiency is covered by legislation that has been enacted by states. However, their legislations are also not very effective, because they, too, do not protect the habitat of species at risk, especially on private land. Such a piecemeal approach results in uneven levels of protection for species-at-risk, which is unacceptable from the conservation viewpoint.

The lack of effective protection of species-at-risk in US is raising controversy. Governments feel the need to demonstrate that they are making rapid progress toward sustainability, an important component of which involves the protection of native species and their habitats. Unfortunately, the progress to date has been lacking and is not yet effective in protecting our biodiversity most at-risk. Hopefully, the lobbying efforts of non-governmental organizations (NGOs) will result in appropriate changes to the currently weak legislation of all levels of government.

Most of the natural ecosystems of the United States now exist only as small remnants of their former extent. Because of this, they are as endangered as the species they support. The most endangered of our natural ecosystems are:

- the tall-grass prairie of the Midwest
- old-growth forests of all of the US
- dry coastal forests of the southeast
- deserts of the southwest
- most freshwater wetlands

Some of these ecosystems are also rich in endangered species. It is imperative that the remaining areas of these endangered ecosystems become preserved in parks and other kinds of protected areas.

Video



In this 3 min video, you will be introduced to the argument that biodiversity loss results in economic loss in diverse ways, therefore natural resource management practices need to be applied.
Question after watching: Do you agree that biodiversity loss should be treated with natural resource management practices? What are the advantages and disadvantages of doing this?

Indigenous Connections: Preserving Salmon Fisheries

"Pacific salmon—fish known by a host of Indigenous names throughout their vast geographic range (genus Oncorhynchus)—have been in a state of decline in British Columbia (BC), Canada for several decades (Price et al. 2017) such that a growing number of wild salmon populations have been assessed as "at risk"' (from Special Concern (n = 5 populations) to Threatened (n = 3) to Endangered (n = 10)) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; Government of Canada 2018). As both ecological and cultural keystone species, without the continued existence of salmon, ecosystems and societies alike would be entirely transformed (Willson and Halupka 1995; Garibaldi and Turner 2004)."[1]

"For the Nisga'a, which sits on the BC–Alaska border (and to which the lead author belongs), salmon are vital. They shape *ayuukhl* (code of law) and *adaawak* (oral histories), they figure centrally in *yukw* (feasts, known externally as "potlatches"), and they are a focal point of the Nisga'a Treaty (2000) that defines Nisga'a rights tied specifically to salmon. As Nisga'a and indeed many Indigenous nations identify as "Salmon People" (Columbia River Inter-Tribal Fish Commission 2020; Earth Economics 2021), there is serious concern about what will become of salmon-linked cultures, economies, knowledges, languages, laws, well-being, and worldviews as the annual return of these anadromous fish to rivers across the Pacific Northwest become increasingly unpredictable and, in many systems, Indigenous fisheries for wild salmon become a shadow of their former selves (Jacob, McDaniels and Hinch 2010; Atlas et al. 2021). Decolonial research strategies that respect Indigenous intellectual traditions and affirm Indigenous control over Indigenous knowledge are critical to the maintenance and recovery of salmon-based knowledge systems and salmon populations (Simpson 2004; Bingham et al. 2021)."[1]

> *Not only would it behoove fisheries scientists to use all and the best tools and knowledge available at this time of [social-ecological] crisis, irrespective of their origin and the perceived objectivity and superiority of Western scientific approaches, but this would importantly serve decolonial and reconciliatory efforts that help rectify uneven power relations, knowledge inequalities, and other racially linked and unjust dynamics in fisheries.*[3]

"Indigenous peoples have been managing landscapes more or less sustainably for thousands of years. Indigenous peoples' successes stem, in part, from the fact that many Indigenous worldviews recognize that species do not exist in isolation; they are part of a natural system."[2]

"TEK provides invaluable time-tested resource management practices that can be used alongside WS to develop more workable and effective approaches to current resource management strategies than either could accomplish alone. In fact, it has become a policy requirement in Canada, and in particular Northern Canada, that TEK be incorporated into environmental assessments affecting wildlife management including: migratory birds, species at risk, forest practices, and fisheries management (Usher, 2000)."3

The Nisga'a Nation's understanding of, and work with, Pacific salmon is an excellent example of the role that Indigenous Science plays in understanding biodiversity and how to protect species and habitat in a sustainable manner.

"Through partnerships with 18 communities of "Salmon People" and semi-structured interviews with 48 knowledge holders (i.e., Elders), we learned that, on average, Elders spent more than half of a century actively engaged in salmon fishing and processing. Modern salmon catches are reported to be approximately one-sixth of what they were estimated to be five to seven decades ago, and the top five threats to salmon identified by Elders included (i) aquaculture, (ii) climate change, (iii) contaminants, (iv) industrial development, and (v) infectious diseases. Threat priorities varied regionally, reflecting distinct lived experiences and regional variation in the prevalence and impact of different threats. Elders perceived threats to salmon

equally as threats to aquatic health and human well-being, with evidence that the relationships between people and water, and salmon and people, are being profoundly transformed."[1]

"The Nisga'a people of northern British Columbia live in the Nass Valley near Alaska. Every spring, members of some Nisga'a families still walk their salmon streams to ensure that spawning channels are clear of debris and that salmon are not obstructed in their ascent to spawning grounds. Concerned with the multiple perils faced by their Nass River salmon, the Nisga'a have themselves implemented a salmon protection project that uses both the ancient technology and wisdom practices, as well as modern statistical methods of data analysis to provide more reliable fish counts than electronic tracking systems (Figure 7.4.1). The Nisga'a project, which earned a Department of Fisheries and Oceans Canada award, is described in the following account by Corsiglia and Snively (1997)

> *"Observing that electronic fish counters can be inaccurate, the Nisga'a have instituted an ingenious fish counting system in the Nass River that combines ancient fish wheel technology with modern statistical methods. The ancient fish wheel was made of cedar wood and nettle fibre mesh, and the elongated axle of the fish wheel was fitted with three parallel vanes constructed in the form of large, flattened dip nets. The swift moving downstream current turned the wheel by exerting force against the submerged vanes, and as the companion vanes rose in turn, they gently caught and uplifted the fish as they swam upriver. As each vane rose from the horizontal, the fish slid toward wooden baffles that guided them out of the side of the fish wheel and into submerged holding baskets. This technology provided the Nisga'a with an effortless fishing technique as well as a ready supply of fresh salmon."[3] (p. 19)*

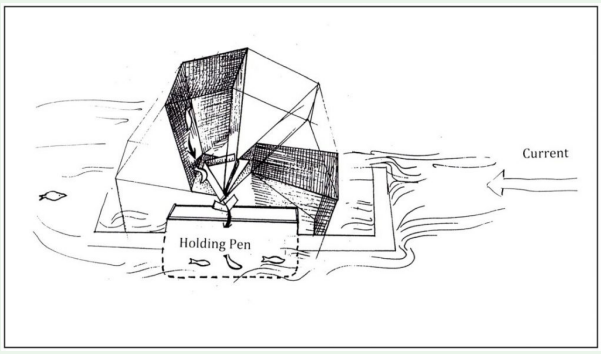


Figure 7.4.1. *Nisga'a fish wheel showing holding pen. Illustration by Laura Corsiglia (1997).*

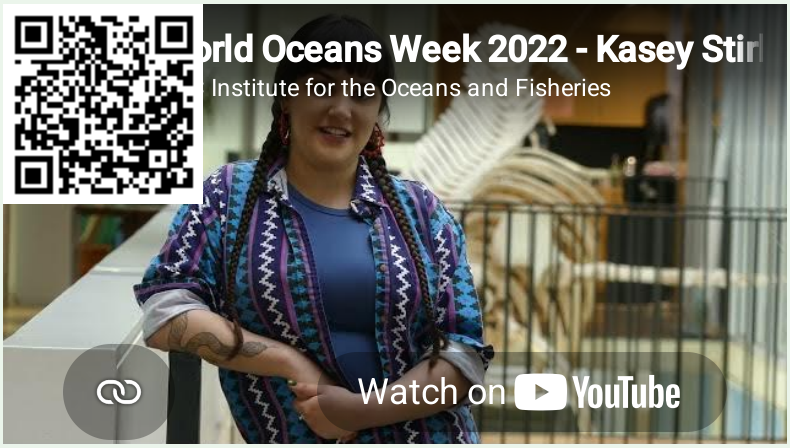
"Modern Nisga'a fishing wheels are made of aircraft aluminum and nylon mesh. Like their predecessors, these fish wheels allow fish to be captured live and held in holding tanks. This enables the Nisga'a to tag and count the fish by means of statistical analysis. Returning salmon are first caught using a fish wheel at a lower river station where fish are tagged. Fish are also caught at an upper fish station where the proportion of tagged fish is used to calculate returns. Reportedly, "this system provides more accurate and reliable data than that collected by electronic tracking systems alone" (Chief Harry Nyce, personal communication to John Corsiglia, 1986)."[3]

In a similar context, the Wuikinuxv of central British Columbia identify the season's quotas for salmon not only with humans in mind but also with bears. They recognize that not only are the bears an important part of their ecosystem and culture but, if the bears are well-fed with salmon, they are less likely to seek out food in areas where humans live. The forest and other inhabitants that the Wuikinuxv rely on are nourished in one way or another by the remains of the salmon.[2]

"The Wuikinuxv calculate fishing quotas based on salmon availability and existing bear density, assuming that, as salmon populations recover, the bear population will grow until it is limited by some other factor. Salmon and bear numbers are then balanced against the benefits of salmon to human fishers. Spawning targets aim to balance the costs felt by humans and bears, the latter of which encompasses the needs of other beings in the ecosystem. In contrast, Canada manages salmon at the federal

level, while bears are managed provincially, making holistic management difficult. The smaller, more intimate scale of Indigenous management efforts, in contrast, allows closer observation of the landscape...and demonstrates how local knowledge is often undervalued".[2]

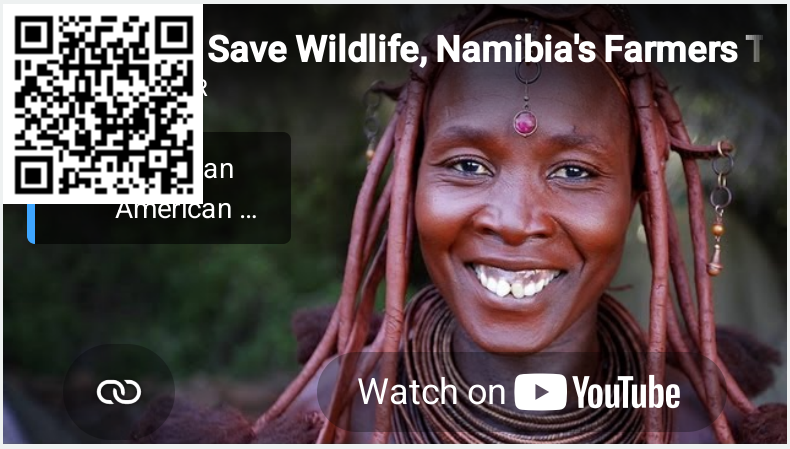
"In a decolonized approach to conservation, the observations of people living in the area would be given proper respect, and systems would be in place to incorporate those observations into models. Another step toward decolonizing conservation...is for settler governments to work with Indigenous communities as equals rather than as just one of many stakeholders. Resource stewardship should be inseparable from Indigenous sovereignty, assert the study's authors."[2]



In this 2.5-minute video, you will meet Kasey Stirling, a Nlaka'pamux, Mi'kmaq, and Acadienne researcher, is a master's student in the Centre for Indigenous Fisheries at the Institute for the Oceans and Fisheries (IOF). Stirling works in partnership with the First Nations Fisheries Legacy Fund, a collective of six Lower Fraser First Nations (Katzie, Kwantlen, Kwikwetlem, Musqueam, Tsleil-Waututh, and Tsawwassen), to co-develop a more culturally relevant framework for watershed health assessment, which directly impacts salmon populations.

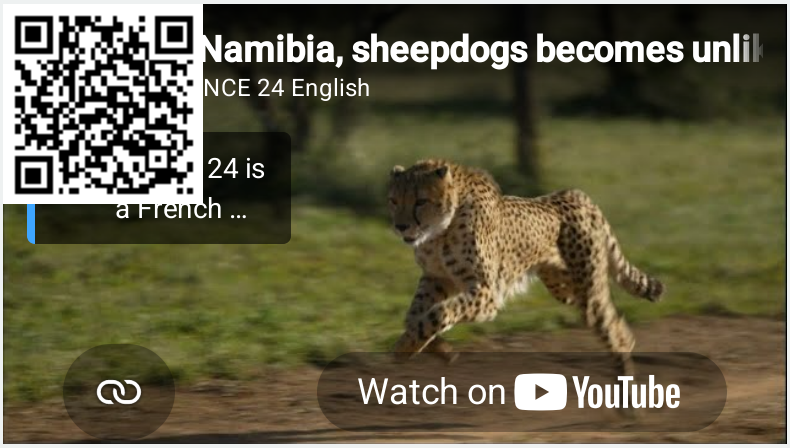
Question after watching: What might be gained from scientists working in partnership with Indigenous communities to preserve diversity? What type of knowledge and perspective can each group bring to the partnership?

Video



Imagine the U.S. government told people who live around Yellowstone, say, all those bears and wolves are now yours to take care of, and for doing that you get to keep the money from tourists who come to see those animals. It can sound radical, but that's essentially what the government of Namibia is doing right now. And as a result, wildlife numbers are rising there - unlike much of Africa.
Question after watching:

Video



Namibia is home to around 3,500 cheetahs, or half the world's cheetah population. But the animals there are threatened by farmers, who often shoot them on sight to defend their herds. To protect the big cats, one wildlife sanctuary had the idea of training sheepdogs.

Question after watching:

Adapting to and Mitigating Climate Change

More on climate change was discussed in Unit 6, but it should be clear to anyone that climate change has the potential to greatly restructure the world's ecosystems, ecosystem services, and national economies. Many coastal areas will experience rising sea levels and increased flooding, while inland areas may experience desertification and less favorable growing conditions for crops. Poorer countries and communities will suffer the consequences disproportionately because of their limited mobility, high dependence on ecosystem services, and general lack of disaster management infrastructure.

If we are to mitigate the far-reaching impacts of climate change, we must carefully monitor and study changes in biological communities and ecosystem functioning, and how they relate to changes in climate and other stressors. While we may lose some species in a warmer world, we can also prevent many extinctions with proactive wildlife management. It is likely that many existing protected areas will no longer preserve some of the rare and threatened species that currently live in them, necessitating careful planning when establishing new protected areas. Even if climate change is not as severe as predicted, the steps we take now to safeguard biodiversity can only help in the future.

The widespread and dramatic impacts of climate change rightfully deserve much attention. But it is also important to remember that we continue to destroy habitats at a massive scale and increasing pace and this loss of habitat is currently the main cause of species extinctions. The highest priorities for conservation must continue to be the preservation of healthy, intact, and connected ecosystems, and the restoration of degraded ecosystems. These actions will simultaneously reduce the impacts of climate change, by reducing carbon emissions, increasing carbon sequestration, and giving wildlife more opportunities to adjust their ranges, in their own time, as the world's climate changes.

Videos

https://bio.libretexts.org/@go/page/105352



Indigenous communities in British Columbia are preparing for climate change, as detailed in this 5-minute video. Question after watching: How are Indigenous communities reconnecting to the land in a changing climate? What other strategies are they utilizing internally and sharing with non-Indigenous communities?

Conservation in Preserves

Video



This 10-minute video by Hank Green provides an overview of both conservation science and restoration efforts, described in further detail below.
Question after watching: What conserved spaces are nearest to you? Do you visit them? Do you know of any restoration efforts near where you live?

The establishment of wildlife and ecosystem **preserves** is one of the key tools in conservation efforts (Figure 7.4.2). 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. Preserves can be effective in the short term for protecting both species and ecosystems, but they face challenges that scientists are still exploring to strengthen their viability as long-term solutions. Human behavior can still be problematic in these areas as well. For example, the public's misbehavior at national parks has become an increasing problem for governments in many countries.



Figure 7.4.2: National parks, such as Kootenay National Park in British Columbia, help conserve biodiversity. (Parks Canada)

Video

https://bio.libretexts.org/@go/page/105352



This 3-minute video from the National Resources Defense Council profiles the importance of Canada's boreal forest and current threats to this ecosystem.
Question after watching: What strategies might be used to preserve these habitats?

US Preservation

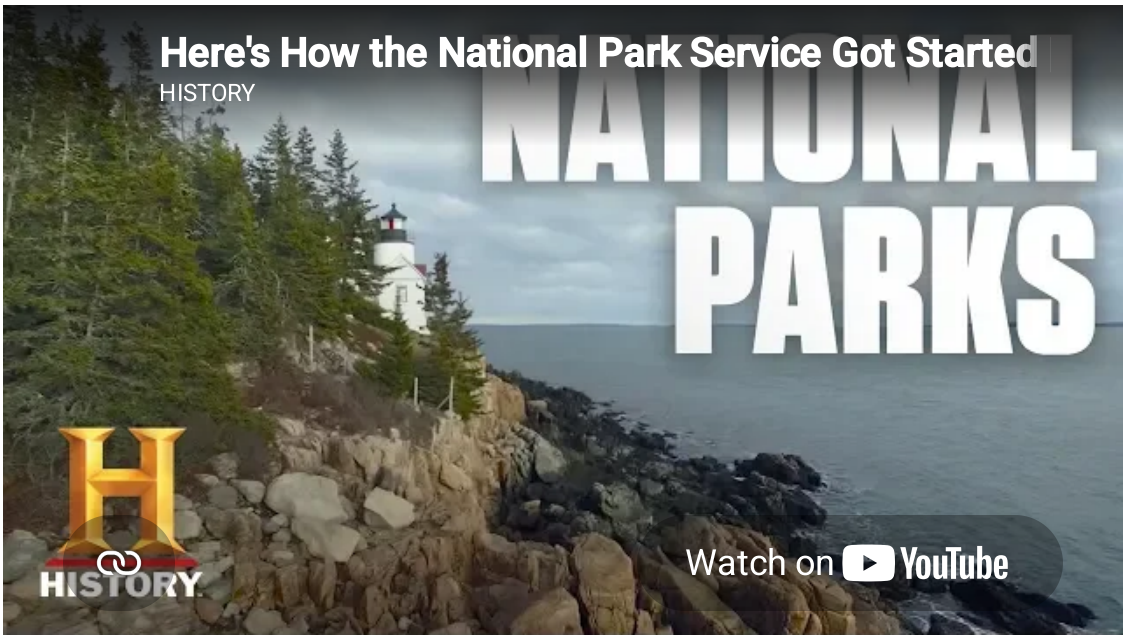
An important human-centered benefit of undeveloped land is their recreational value. Every year, millions of people visit recreational lands such as parks and wilderness areas to experience attractions of the great outdoors: hiking among the giant sequoias in California, traveling on a photo safari in Kenya or just picnicking at a local county park. Besides providing people with obvious health benefits and aesthetic pleasures, recreational lands also generate considerable tourist money for government and local economies.

The United States has set aside more land for public recreational use than any other country. Several different federal organizations provide lands for recreational use: the National Forest System, the U.S. Fish and Wildlife Service, the National Park System and the National Wilderness Preservation System. The National Forest System manages more than 170 forestlands and grasslands, which are available for activities such as camping, fishing, hiking and hunting.

The U.S. Fish and Wildlife Service manage more than 500 National Wildlife Refuges, which not only protect animal habitats and breeding areas but also provide recreational facilities. The National Park System manages more than 380 parks, recreation areas, seashores, trails, monuments, memorials, battlefields and other historic sites. The National Wilderness Preservation System manages more than 630 roadless areas through the aforementioned government services as well as through the Bureau of Land Management.

The **National Park System** consists of more than 80 million acres nationwide. The largest national park is Wrangell-St. Elias National Park and Preserve in Alaska with over 13 million acres. California has eight national parks: Channel Islands, Death Valley, Joshua Tree, Lassen, Redwood, Sequoia, Kings Canyon and Yosemite. Many national parks such as Yosemite, Yellowstone and the Grand Canyon are such popular recreation destinations that the ecosystems of those parks are being severely tested by human activities.

In addition to their primary goal of conserving biodiversity, most parks serve additional purposes, including the support of economically important outdoor recreation and tourism. To some degree, the use of parks for these purposes is a challenge to their ability to function as ecological reserves. For example, strictly interpreted, the ecological values of national parks are not compatible with consumptive uses of their natural resources (such as sport fishing) or with the development of infrastructure to support recreation and tourism (such as campgrounds, golf courses, hotels, roads, ski facilities, and even interpretation facilities).


Here's How the National Park Service Got Started
HISTORY
NATIONAL PARKS
HISTORY
Watch on YouTube


NATIONAL PARKS
HISTORY


Who owns the "wilderness"? - Elyse Cox
TED-Ed
TEDEd
NATIONAL PARKS
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Every state has also set aside significant amounts of land for recreational use. The California State Park System manages more than one million acres of parklands including: coastal wetlands, estuaries, scenic coastlines, lakes, mountains and desert areas. California's largest state park is Anza-Borrego Desert State Park, which is the largest state park in the United States with 600,000 acres. The stated mission of the California State Park System is: "To provide for the health, inspiration and education of the people of California by helping to preserve the state's extraordinary biological diversity, protecting its most valued natural and cultural resources and creating opportunities for high-quality outdoor recreation."

This is the basic goal of all recreational lands: to manage and conserve natural ecosystems, while supporting a sustainable and balanced level of human use of those areas. Unfortunately, it is a goal which is sometimes difficult to achieve due to the increasing popularity and use of recreational lands.

The "**Wilderness Act of 1964**" created the world's first wilderness system in the United States. Presently, the **National Wilderness Preservation System** contains more than 100 million acres of land that will forever remain wild. A wide range of recreation, scientific and outdoor activities are available in wilderness lands. Mining operations and livestock grazing are permitted to continue in certain wilderness areas where such operations existed prior to an area's designation. Hunting and fishing are also allowed in wilderness areas (except in national parks).

For most people, wilderness lands provide a means for various forms of recreation: hiking, horseback riding, bird watching, fishing, and hunting. People can escape the stress of modern-day life and enjoy an undisturbed look at nature. Wilderness lands provide an essential habitat for a wide array of fish, wildlife, and plants, and are particularly important in protecting endangered species. For scientists, wilderness lands serve as natural laboratories, where studies can be performed that would not be possible in developed areas.

Several other types of public lands complement the designated wilderness land system. These include: national forest roadless areas, national trails system, natural research areas and state and private wilderness lands. The national forest roadless areas consist of millions of acres of wild, undeveloped land without roads that exist on National Forest land outside of designated wilderness lands.

The "**National Trail System**," established by Congress in 1968, includes trails in wilderness areas and other public lands. **Research Natural Areas** located throughout the country on public lands serve as outdoor laboratories to study natural systems. They are intended in part to serve as gene pools for rare and endangered species and as examples of significant natural ecosystems. Some wilderness lands are maintained by states or private organizations. For example, the state of New York has long preserved a region of the Adirondacks as wilderness.

In addition to their primary goal of conserving biodiversity, most parks serve additional purposes, including the support of economically important outdoor recreation and tourism. To some degree, the use of parks for these purposes is a challenge to their ability to function as ecological reserves. For example, strictly interpreted, the ecological values of national parks are not compatible with consumptive uses of their natural resources (such as sport fishing) or with the development of infrastructure to support recreation and tourism (such as campgrounds, golf courses, hotels, roads, ski facilities, and even interpretation facilities).

The ecological-reserve function of many protected areas is also threatened by land-use and management activities that are occurring in their surrounding area. Usually, the most important of the “external” stressors are associated with agriculture, forestry, mining, tourism, or hydroelectric development. In fact, all of the national parks in more southern regions of Canada are significantly threatened in this way.

Banff National Park in southwestern Alberta was the first national park to be established in Canada, in 1885. The original intent was to protect extremely scenic views and hot springs and to develop the area in support of the economic benefits of tourism. It was not until several decades later that the philosophical underpinning of national parks shifted toward the protection of natural values. In any event, the early development of Banff featured the enthusiastic construction of large hotels, golf courses, skiing facilities, major highways, a transcontinental railroad, several villages, and other structures. This pattern continues today with much ongoing construction, coupled with rapid development of the area east of the park for tourism, residential neighborhoods, forestry, and other uses. These facilities severely threaten the long-term viability of the natural values of Banff.

Provincial and territorial governments also have a responsibility to protect natural values within their jurisdiction. These governments have designated many ecological reserves and wilderness areas, supplemented by natural areas that are protected in provincial parks and conservation areas, which are also well-used for recreation. Some municipalities also have natural-area parks that provide habitat for native species. An outstanding example is the city of Windsor, Ontario, which is protecting important remnants of tall-grass prairie and Carolinian forest, and their many species-at-risk.

How Much Area to Preserve?

Due to the way protected lands are allocated (they tend to contain less economically valuable resources rather than being set aside specifically for the species or ecosystems at risk) and the way biodiversity is distributed, determining a target percentage of land or marine habitat that should be protected to maintain biodiversity levels is challenging. The IUCN World Parks Congress estimated that 11.5% of Earth’s land surface was covered by preserves of various kinds in 2003. This area is greater than previous goals; however, it only represents 9 out of 14 recognized major biomes. Research has shown that 12% of all species live only outside preserves; these percentages are much higher when only threatened species and high-quality preserves are considered. For example, high-quality preserves include only about 50% of threatened amphibian species. The conclusion must be that either the percentage of area protected must increase, the percentage of high-quality preserves must increase, or preserves must be targeted with greater attention to biodiversity protection. Researchers argue that more attention to the latter solution is required.

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. Protecting hotspots would be able to protect a larger number of species. The original criteria for a hotspot included the presence of 1,500 or more species of endemic plants and 70 percent of the area disturbed by human activity. While many have still not been conserved, there are now 34 identified global biodiversity hotspots (Figure 7.4.3) that contain large numbers of endemic species, which include half of Earth’s endemic plants. In addition to natural spaces, there are numerous human cultural sites preserved in the **UNESCO World Heritage Sites** list: https://whc.unesco.org/en/list/

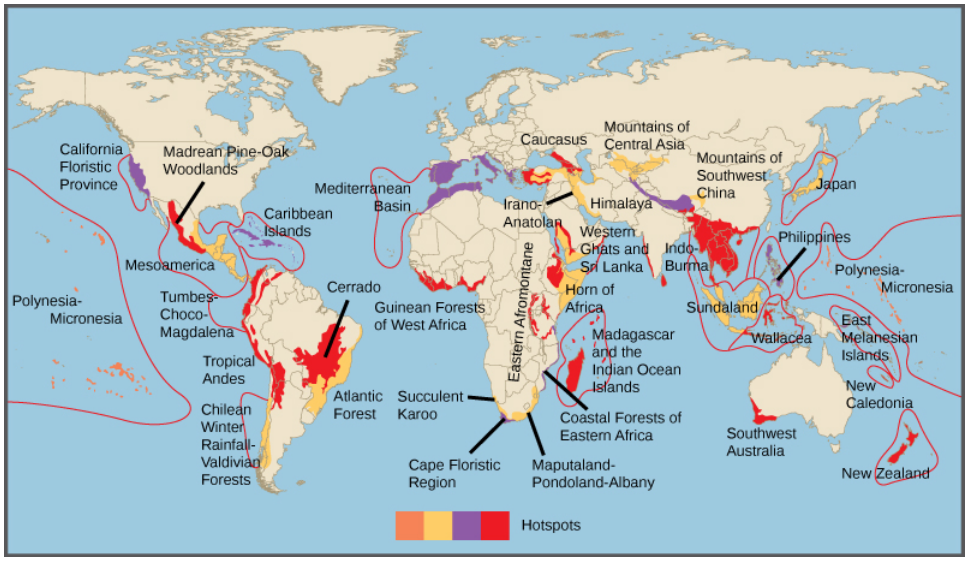


Figure 7.4.3. Conservation International has identified 34 biodiversity hotspots. Although these cover only 2.3 percent of the Earth's surface, 42 percent of the terrestrial vertebrate species and 50 percent of the world's plants are endemic to those hotspots.

? Optional Activity 7.4.2

Scientists are evaluating an island ecosystem for consideration as a biodiversity hotspot. What information should they collect and evaluate as part of their fieldwork to produce their final assessment?

a. the total number of endemic species in an ecosystem
b. the total number of organisms in an ecosystem
c. the total number of species divided by the area of the ecosystem
d. the total number of endangered species in an ecosystem

Answer

A. the total number of endemic species in an ecosystem.

Preserve Design

There has been extensive research into optimal preserve designs for maintaining biodiversity. The fundamental principle behind much of the research has been 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. The fundamental conclusion was that biodiversity on an island was a function of the origin of species through migration, speciation, and extinction on that island. Islands farther from the mainland are harder to get to, so migration is lower and the equilibrium number of species is lower. Within island populations, evidence suggests that the number of species gradually increases to a level similar to the numbers on the mainland from which the species is suspected to have migrated. In addition, smaller islands are harder to find, so their immigration rates for new species are lower. Smaller islands are also less geographically diverse so there are fewer niches to promote speciation. And finally, smaller islands support smaller populations, so the probability of extinction is higher.

As islands get larger, the number of species accelerates, although the effect of island area on species numbers is not a direct correlation. Conservation preserves can be seen as "islands" of habitat within "an ocean" of non-habitat. For a species to persist in a preserve, the preserve must be large enough. The critical size depends, in part, on the home range that is characteristic of the species. A preserve for wolves, which ranges hundreds of kilometers, must be much larger than a preserve for butterflies, which might range within ten kilometers during its lifetime. But larger preserves 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.

Preserves perform better when there are buffer zones around them of suboptimal habitat. The buffer allows organisms to exit the boundaries of the preserve without immediate negative consequences from predation or lack of resources. One large preserve is

better than the same area of several smaller preserves because there is more core habitat unaffected by edges. 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 between them so that individuals and their genes can move between the preserves, for example along rivers and streams, will make the smaller preserves behave more like one large one. 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, biological, and ecological specifications of a preserve, there are a variety of policy, legislative, and enforcement specifications related to the uses of the preserve for functions other than the protection of species. These can include anything from timber extraction, mineral extraction, regulated hunting, human habitation, and non-destructive human recreation. Many of these policy decisions are made based on political pressures rather than conservation considerations. 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 areas of the tropics.

? Optional Activity 7.4.3

A preserve design is proposed for a densely populated suburban area. Which overall design plan would be best for preservation of local ecosystems?

A. Set up many, small, unconnected, protected areas.
B. Select one, small area that is isolated from residences.
C. Plan buffer zones around all backyard spaces.
D. Set up several, connected, larger areas to be set aside for natural ecosystems.

Answer

D. Set up several, connected, larger areas to be set aside for natural ecosystems.

Limitations on Preserves

Some of the limitations of preserves as conservation tools are evident from the discussion of preserve design. Political and economic pressures typically make preserves smaller, never larger, so setting aside areas that are large enough is difficult. If the area set aside is sufficiently large, there may not be sufficient area to create a buffer around the preserve. In this case, an area on the outer edges of the preserve inevitably becomes a riskier suboptimal habitat for the species in the preserve. Enforcement of protections is also a significant issue in countries without the resources or political will to prevent poaching and illegal resource extraction.

Climate change will create inevitable problems with the location of preserves. The species within them will migrate to higher latitudes as the habitat of the preserve becomes less favorable. Scientists are planning for the effects of global warming on future preserves and striving to predict the need for new preserves to accommodate anticipated changes to habitats; however, the end effectiveness is tenuous since these efforts are prediction-based.

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 holds considerable promise as a mechanism for restoring and maintaining biodiversity. Of course, once a species has become extinct, its restoration is impossible. However, **restoration** can improve the biodiversity of degraded ecosystems. Reintroducing wolves, a top predator, to Yellowstone National Park in 1995 led to dramatic changes in the ecosystem that increased biodiversity (Figure 7.4.4).

The wolves, a keystone species, function to suppress elk and coyote populations and provide more abundant resources to the guild of carrion eaters. Reducing elk populations has allowed the revegetation of riparian areas, which has increased the diversity of species in that habitat. Decreasing the coyote population has increased the populations of species that were previously suppressed by this predator. The number of species of carrion eaters has increased because of the predatory activities of the wolves.

The results from the Yellowstone experiment suggest that restoring a keystone species 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 those species; likewise, it also makes sense to attempt to return them to their ecosystem if they have been removed.

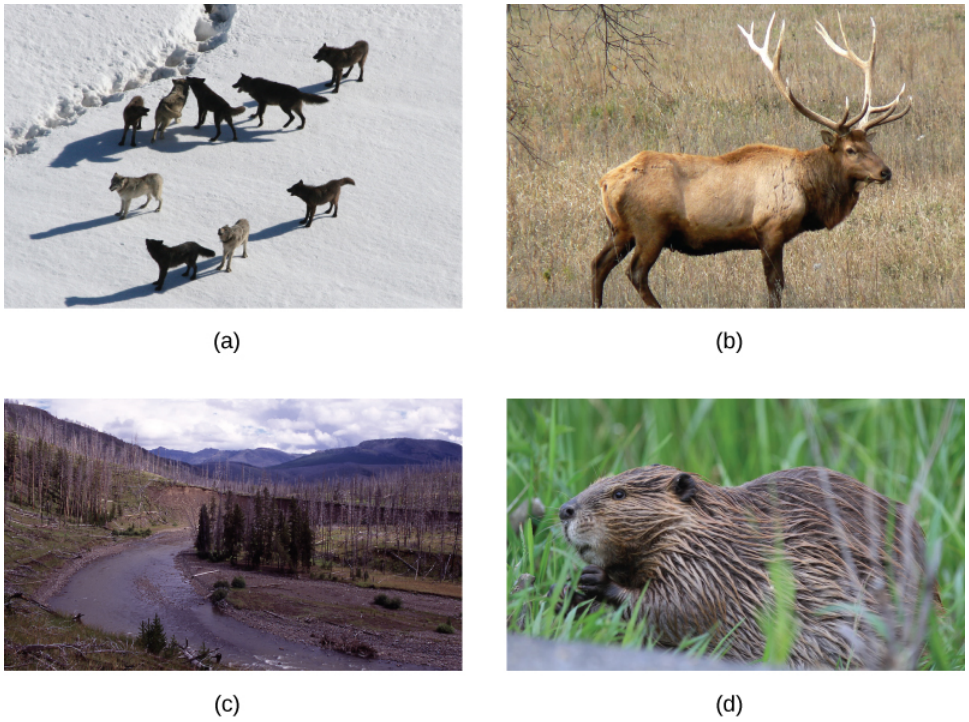


Figure 7.4.4: (a) The Gibbon wolf pack in Yellowstone National Park, March 1, 2007, represents a keystone species. The reintroduction of wolves into Yellowstone National Park in 1995 led to a change in the grazing behavior of (b) elk. To avoid predation, the elk no longer grazed exposed stream and riverbeds, such as (c) the Lamar Riverbed in Yellowstone. This allowed willow and cottonwood seedlings to grow. The seedlings decreased erosion and provided shading to the creek, which improved fish habitat. A new colony of (d) beaver may also have benefited from the habitat change. (credit a: modification of work by Doug Smith, NPS; credit c: modification of work by Jim Peaco, NPS; credit d: modification of work by “Shiny Things”/Flickr)

Other large-scale restoration experiments underway involve dam removal. 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 and because many dams no longer provide the benefit and functions that they did when they were first built. The measured benefits of dam removal include restoration of naturally fluctuating water levels (the purpose of dams is frequently to reduce variation in river flows), which leads to increased fish diversity and improved water quality.

On the Pacific coast, dam removal projects are expected to increase populations of salmon, which is considered a keystone species because it transports key 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 freshwater, live most of their lives in salt water, and return to freshwater to spawn). Some of the largest dam removal projects have yet to occur or have happened too recently for the consequences to be measured. The large-scale ecological experiments that these removal projects constitute will provide valuable data for other dam projects slated either for removal or construction.

CHAPTER OVERVIEW

9: Food Security and 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

9.1: Conventional Agriculture
9.2: Soil Profiles, Processes, and Plant Interactions
9.3: Pests and Pesticides
9.4: Biotechnology and Genetic Engineering
9.5: Sustainable Agriculture
9.6: Food Security
9.S: Food and Agriculture (Summary)

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9.1: 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 9.1.1. 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 by Kimberly 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.

Water Use and Pollution

Agriculture is the single largest user of water in the world. Most of that water is used for irrigating crops. **Irrigation** is the process of transporting water from one area to another for the purpose of growing crops. The water used for irrigation usually comes from rivers or from groundwater pumped from wells. The main reason for irrigating crops is that it increases yields. It also allows the farming of marginal land in arid regions that would normally not support crops. There are several methods of irrigation: flood irrigation, furrow irrigation, drip irrigation, and center pivot irrigation.

Flood irrigation involves the flooding of a crop area located on generally flat land. This gravity flow method of water is relatively easy to implement, especially if the natural flooding of river plains is utilized, and therefore is cost-effective. However, much of the water used in flood irrigation is lost, either by evaporation or by percolation into soil adjacent to the intended area of irrigation. Because farmland must be flat for flood irrigation to be used, flood irrigation is only practical in certain areas (e.g., river flood plains and bottomlands). In addition, because land is completely flooded, salts from the irrigation water can build up in the soil, eventually rendering it infertile.

Furrow irrigation also involves the gravity flow of water on relatively flat land. However, in this form of irrigation, the water flow is confined to furrows or ditches between rows of crops. This allows better control of the water and, therefore, less water is needed and less is wasted. Because water can be delivered to the furrows from pipes, the land does not need to be completely flat. However, furrow irrigation involves higher operating costs than flood irrigation due to the increased labor and equipment required. It, too, involves large evaporative loss.

Drip irrigation involves delivering small amounts of water directly to individual plants. Water is released through perforated tubing mounted above or below ground near the roots of individual plants. This method was originally developed in Israel for use in arid regions having limited water available for irrigation. It is highly efficient, with little waste of water. Some disadvantages of drip irrigation are the high costs of installation and maintenance of the system. Therefore, it is only practical for use on high-value cash crops.

Center-pivot sprinkler systems deliver water to crops from sprinklers mounted on a long boom, which rotates about a center pivot. Water is pumped to the pivot from a nearby irrigation well. This system has the advantage that it is very mobile and can be moved from one field to another as needed. It can also be used on uneven cropland, as the moving boom can follow the contours of the land. Center-pivot systems are widely used in the western plains and southwest regions of the United States. With proper management, properly designed systems can be almost as efficient as drip irrigation systems. Center-pivot systems have high initial costs and require a nearby irrigation well capable of providing a sufficiently high flow. Constant irrigation with well water can also lead to salinization of the soil.

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 the manufacture, processing, and distribution of farm products - into fewer and fewer hands. Market competition is limited, and farmers have little

control over the 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 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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9.2: Soil Profiles, Processes, and Plant Interactions

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 9.2.1). 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.

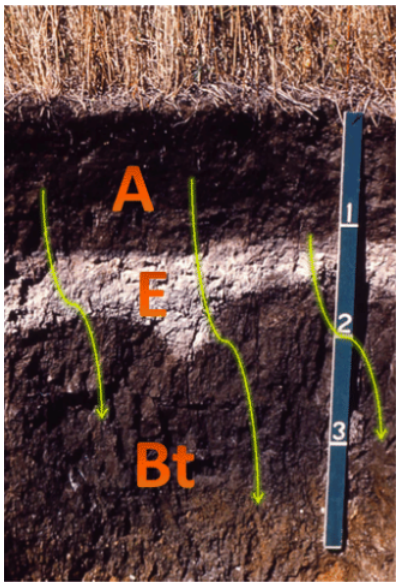


Figure 9.2.1. Soil Profile. Photograph shows a soil profile from South Dakota with A, E, and Bt horizons. The yellow arrows symbolize translocation of fine clays to the Bt horizon. The scale is in feet. Source: University of Idaho and modified by D. Grimley.

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 9.2.2) 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.

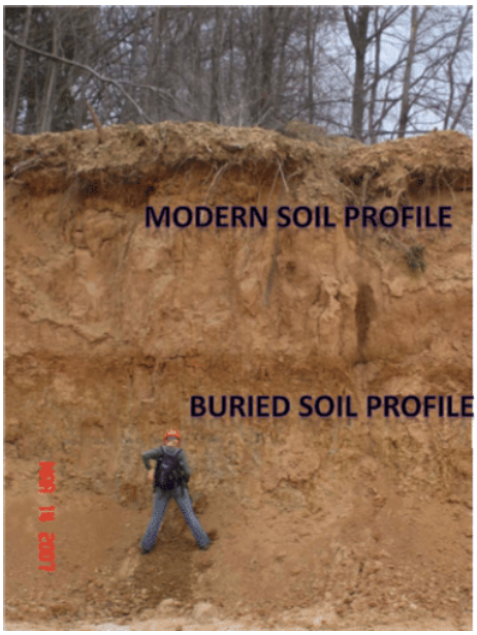


Figure 9.2.2. Modern versus Buried Soil Profiles. A buried soil profile, or paleosol (above geologist ‘s head), represents soil development during the last interglacial period. A modern soil profile (Alfisol) occurs near the land surface. Source: D. Grimley.

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 9.2.3).

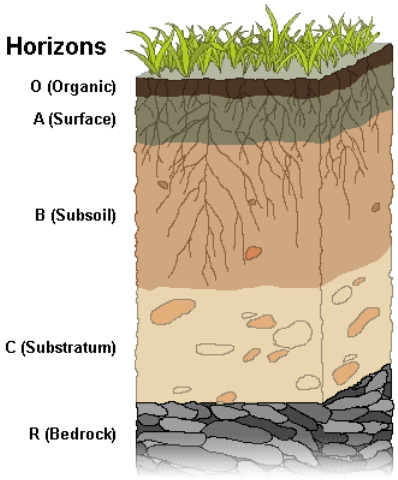


Figure 9.2.3. This images shows the different horizons, or layers, in soil. *This work by Wilsonbiggs is licensed under CC BY-SA 4.0*

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.

Soil plays a key role in plant growth. Beneficial aspects to plants include providing physical support, water, heat, nutrients, and oxygen (Figure 9.2.1). 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.

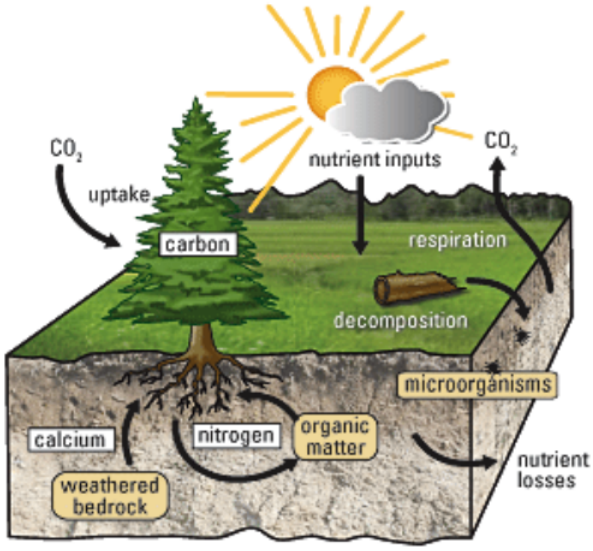


Figure 9.2.1. Soil-Plant Nutrient Cycle. This figure illustrates the uptake of nutrients by plants in the forest-soil ecosystem. Source: U.S. Geological Survey.

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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9.3: 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 9.3.1. 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 9.3.2). 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.

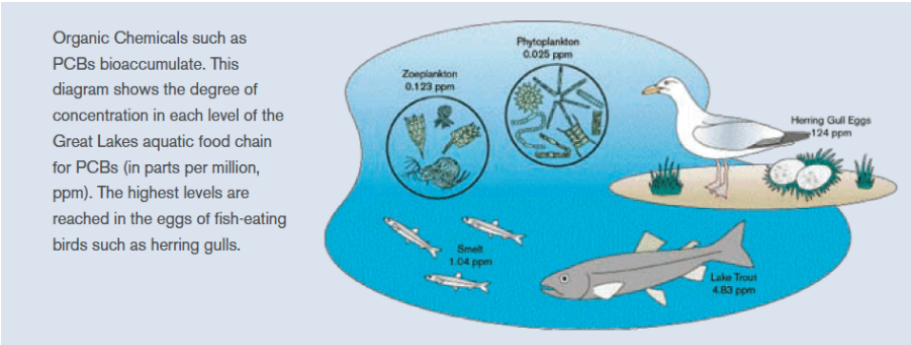


Figure 9.3.2. Bioaccumulation and biomagnification. U.S. EPA. Great Lakes: The Great Lakes Atlas: Chapter Four the Great Lakes Today – Concerns. January 2009

“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 9.3.3, 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.

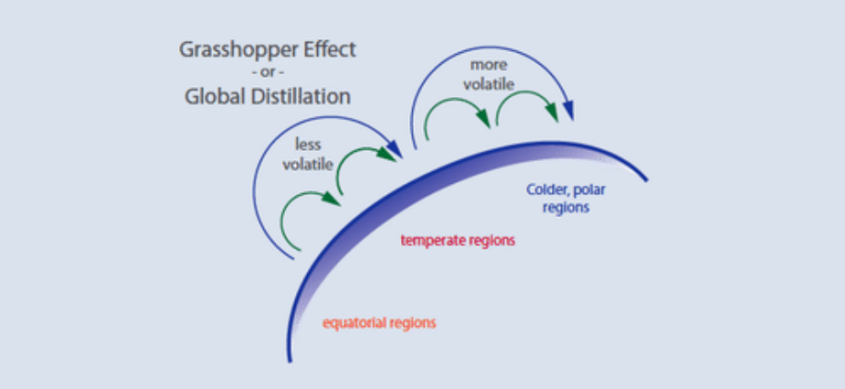


Figure 9.3.3. How POPs move throughout the environment. Source: Environment Canada. The Science and the Environment Bulletin. May/June 1998

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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9.4: 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 9.4.1). 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.

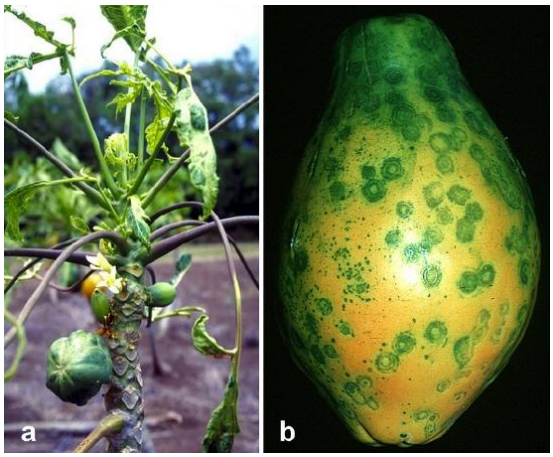


Figure 9.4.1. The symptoms of papaya ringspot virus are shown on the tree (a) and fruit (b). *"This work" is in the Public Domain, CC0.*

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?

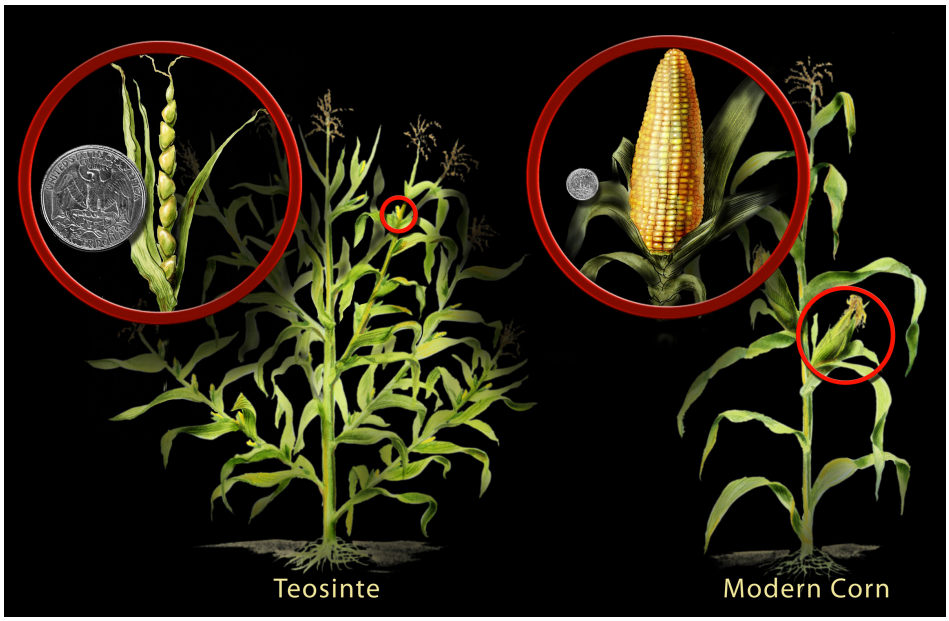


Figure 9.4.2. A wild grass called teosinte was genetically modified through selective breeding to produce what is now known as maize (corn). This process of transformation started thousands of years ago by indigenous people of what is now Mexico. *"This work" by Nicolle Rager Fuller, National Science 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 9.4.2). 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 9.4.3. 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 9.4.3). 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.

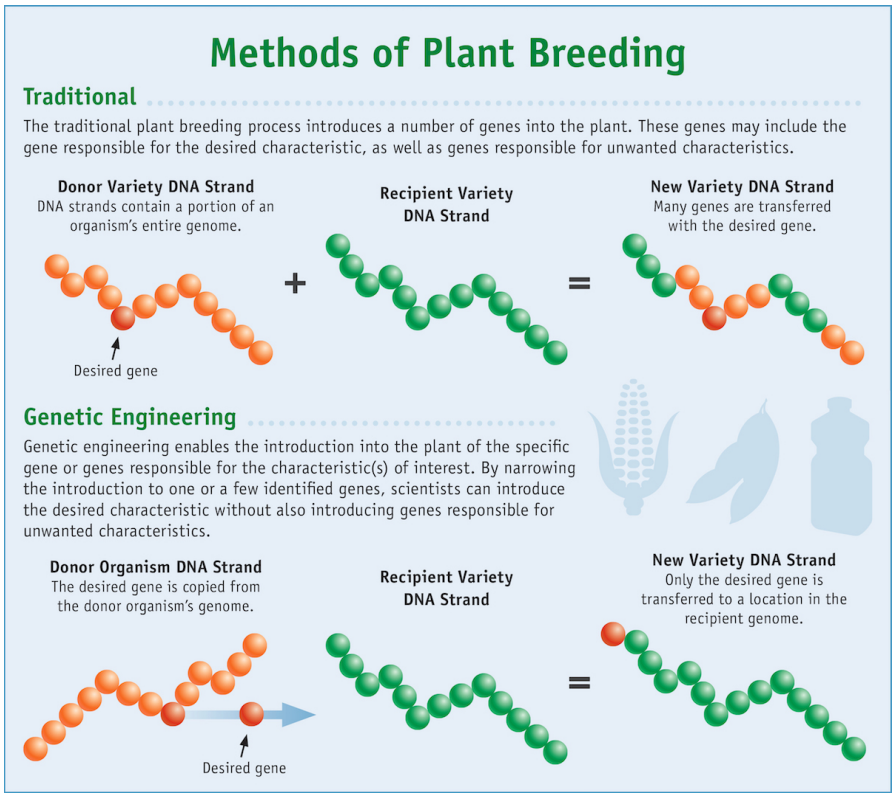


Figure 9.4.4. Both traditional breeding and modern genetic engineering produce genetic modifications. Genetic engineering allows for fewer and more precise genetic modifications. FDA graphic by Michael J. Ermarth (Methods of Plant Breeding) [CC0 Public Domain], via Wikimedia Commons.

Potential Benefits of Genetic Engineering

Enhanced nutrition

Advances in biotechnology may provide consumers with foods that are nutritionally-enriched (Figure 9.4.4), 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 9.4.5. 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 9.4.6. 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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9.5: 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 9.5.1). 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 9.5.1. 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 9.5.2). 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 9.5.2. 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 9.5.3).



Figure 9.5.3. 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.

Urban Farming

Small community gardens, urban farms that span several city blocks, and intensive indoor hydroponic or aquaculture facilities are all examples of urban agriculture. This fast-growing phenomenon has the potential to nourish the health and social fabric of communities while creating economic opportunities for farmers and neighborhoods. However, it also comes with a unique set of challenges (e.g., unique legal and zoning regulations as well as social stigma and lack of education and space) and many opportunities. Urban farmers, federal and city government agencies, and local organizations around the country have developed a variety of tools to help address those challenges and assist the growth of agriculture in cities.

Whether it is a for-profit, a non-profit, a sole proprietorship, a partnership, or a cooperative, urban farms are businesses and need to understand legal issues that could affect the business. On the other hand, small community volunteer gardens may only need to comply with zoning regulations and building support in their community.

Access to land and water is one of the biggest challenges facing new farmers and farmers looking to expand their operations across the country. Land access is particularly challenging in urban areas, where vacant land suitable or access to water sources for farming is often not available. Sometimes appropriate land exists but it may be difficult to transfer to urban growers.

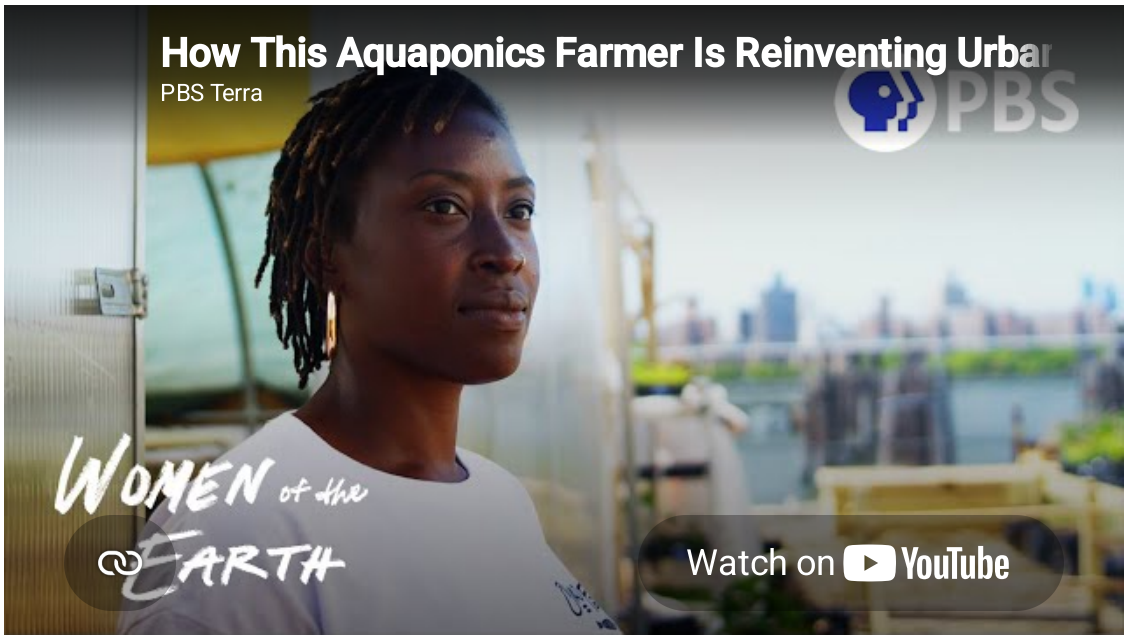
Ensuring healthy soils is not only critically important, but difficult in urban settings, where soil can be contaminated by multiple sources – historical use of coal for heat and cooking, pollution from industrial practices and consumer products such as leaded gasoline and lead-based paint, urban fill in low lying areas, pesticide residues, and illegal dumping. Unfortunately, soil testing may be expensive, and determining what to test for may be confusing for urban farmers. Remediation may be expensive and require coordination and collaboration with environmental regulatory agencies, which requires significant time for urban farmers.

Some cities and counties are developing innovative and creative strategies to connect vacant land and lots with interested farmers. There have also been federal resources available to assist with land procurement and soil remediation, but these are less available with the 2025 DOGE budget cuts.





An urban ag story from USDA's Risk Management Agency about a non-profit in St. Paul, Minnesota that promotes urban gardens, conservation and cooking to the community.





Yemi Amu has dedicated her life as a farmer to solving this problem by starting the only aquaponics farm in NYC. Oko Farms in Brooklyn is both a working farm that provides fresh food to surrounding neighborhoods, while also actively engaging the public in education on how to grow food for in urban environments.

"Buy Local": Farmers Markets and Community Supported Agriculture (CSAs)

Food sold close to where it was grown or produced is considered "locally grown." Buying food from local farmers is believed to be good for communities, the local economy, and the environment. Locally sold produce can be harvested at its peak ripeness, and reaches the consumer faster and at a fresher stage. Buying local reduces energy costs, including climate emissions due to food miles, and supports food that grows well in the regional climate. When consumers buy local, more of their money stays in their community.

Local food can be found at farmers markets, restaurants, CSAs, food co-ops, food hubs, food stores, and online.

Farmers' Markets

Farmers' markets are an integral part of communities, and their food systems, economies, and social networks. They are the oldest way that humans have sold food and other goods to each other, gathering in one place to connect with neighbors, meet local farmers, support local businesses, and provide nutritious food to neighborhoods and families. They also provide a space to learn more about the local area, such as library offerings, musicians, artisans, specialty vendors, and more.

There are many benefits of shopping at farmers' markets, including:

- Buying fresh, local produce and other farm-based products (e.g., honey, dairy products, meat, etc.) can help improve the nutritional value and variety of a family's diet,
- The money spent at a Farmers Market stays within the local/regional economy, and
- Speaking directly to farmers who can provide information on choosing, using, preparing, and storing the products they sell.

Community Supported Agriculture





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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9.6: 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 9.6.1).

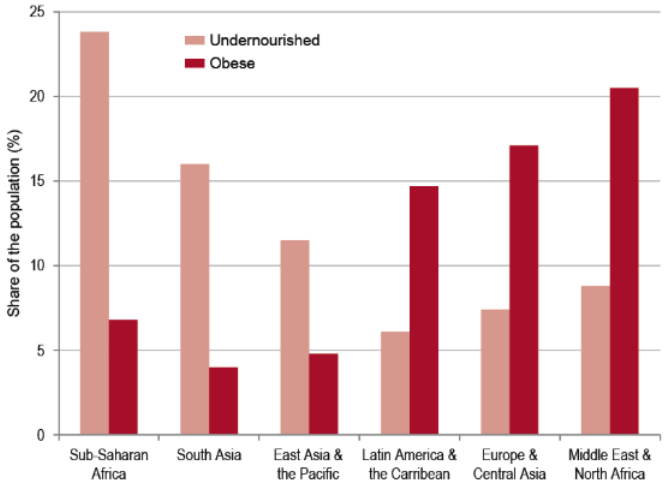


Figure 9.6.1. Obesity and undernourishment by region.

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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9.S: Food and 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.

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

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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