Environmental Biology

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CRYSTAL PEIRCE

CARALYN ZEHNDER, KALINA MANOYLOV, SAMUEL MUTITI, CHRISTINE MUTITI, ALLISON VANDEVOORT, DONNA BENNETT, SILPA KAZA, LISA YAO, PERINAZ BHADA-TATA, AND FRANK VAN WOERDEN, MATTHEW R. FISHER, JEAN BRAINARD, AND HANNAH RITCHIE AND MAX ROSER

Contents

Foreward

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Fisher, Matthew R. "Environmental Biology" (2019). https://www.oercommons.org/courses/environmental-biology/view

Goosse, Hugues, Brainard, Jean, Stewart, Robert, and Rogers-Estable, Michelle, "Introduction to Environmental Science" (2011). https://www.ck12.org/user:bwvzdgfibguzn2vkdubnbwfpbc5jb20./book/introduction-to-environmental-science/

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Ritchie, Hannah and Max Roser "Urbanization" (2018). *Published online at OurWorldInData.org.* Retrieved from: 'https://ourworldindata.org/urbanization' [Online Resource]

Silpa Kaza, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. "What a Waste 2.0" (2018). International Bank for Reconstruction and Development. https://www.worldbank.org

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Introduction

Our world is a place of natural beauty and wonder. It is rich in complex living layers – from the soil below our feet to the nature that surrounds us to the air above us, this living, breathing system is based on a delicate balance. This balance depends on the careful movement of nutrients like water, carbon, and energy in and through living and non-living things around us. A web of life hangs in this balance and it doesn't take much to upset it. Humans are one of the greatest agents of change this planet has ever seen. Our unsustainable use of natural resources, exponentially growing population, and patchwork of environmental policies have put our environment at risk. The risk is greatest for the rich and diverse types of living things, but our own behaviors are also putting human populations at risk. Climate change and pollution are putting a strain on our water resources making it harder to feed our ever growing population. Our destruction of habitats not only means we lose species, but also the potential for discoveries in medicine, agriculture, and industry that may be key to our survival.

Amidst the challenges there are opportunities. There is a path forward where we can meet the needs of humans and also protect the environment. There are changes to be made at every level, including international cooperation, challenging standard business practices, and even promoting individual behaviors. The environmental biology courses at Harper College are meant to inform students about the problems the planet faces but also to highlight the continual progress being made to protect and preserve what we can. The topics found in this book cover the basics of environmental biology and along with supplemental information provided by your instructor, should give you a solid foundation to begin your studies.

1. Introduction to Environmental Science

CARALYN ZEHNDER, KALINA MANOYLOV, SAMUEL MUTITI, CHRISTINE MUTITI, ALLISON VANDEVOORT, DONNA BENNETT

Environment and environmental science

Viewed from space, Earth **(Figure 1.1)** offers no clues about the diversity of lifeforms that reside there. The first forms of life on Earth are thought to have been microorganisms that existed for billions of years in the ocean before plants and animals appeared. The mammals, birds, and plants so familiar to us are all relatively recent, originating 130 to 200 million years ago. Humans have inhabited this planet for only the last 2.5 million years, and only in the last 200,000 years have humans started looking like we do today. There are around 7.35 billion people today (https://www.census.gov/popclock/).

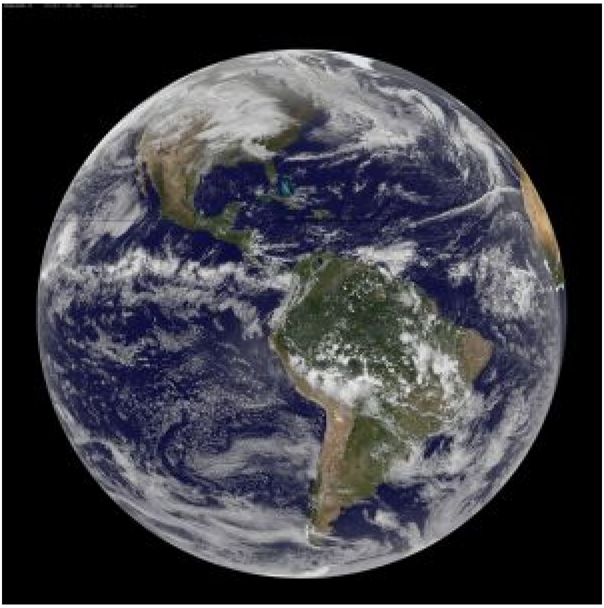


Figure 1.1 This NASA image is a composite of several satellite-based views of Earth. To make the whole-Earth image, NASA scientists combine observations of different parts of the planet. (credit: NASA/GSFC/NOAA/USGS)

The word **environment** describes living and nonliving surroundings relevant to organisms. It incorporates physical, chemical and biological factors and processes that determine the growth and survival of organisms, populations, and communities. All these components fit within the ecosystem concept as a way to organize all of the factors and processes that make up the environment. The ecosystem includes organisms and their environment within a specific area. Review the previous section for in-depth information regarding the Earth's ecosystems. Today, human activities influence all of the Earth's ecosystems.

Environmental science studies all aspects of the environment in an **interdisciplinary** way. This means that it requires the knowledge of various other subjects including biology, chemistry, physics, statistics, microbiology, biochemistry, geology, economics, law, sociology, etc. It is a relatively new field of study that has evolved from integrated use of many disciplines. **Environmental engineering** is one of the fastest growing and most complex disciplines of engineering. Environmental engineers solve problems and design systems using knowledge of environmental concepts and ecology, thereby providing solutions to various environmental problems. **Environmentalism,** in contrast, is a social movement through which citizens are involved in activism to further the protection of environmental landmarks and natural resources. This is not a field of science, but incorporates some aspects of environmental knowledge to advance conservation and sustainability efforts.

The Process of Science

The process of science

Environmental science is a science, but what exactly is science? **Science** (from the Latin *scientia,* meaning "knowledge") can be defined as all of the fields of study that attempt to comprehend the nature of the universe and all its parts. The **scientific method** is a method of research with defined steps that include experiments and careful observation. One of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A **hypothesis** is a suggested explanation for an event, which can be tested. A **theory** is a tested and confirmed explanation for observations or phenomena that is supported by many repeated experiences and observations.

The scientific methodThe scientific process typically starts with an observation (often a problem to be solved) that leads to a question. The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed. 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 in 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?"

Proposing a HypothesisRecall 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, the student can make a prediction. 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."

Testing a HypothesisA valid hypothesis must be testable. It should also be falsifiable, meaning that it can be disproven by experimental results. Importantly, science does not claim to "prove" anything because scientific understandings are always subject to modification with further information. This step — openness to disproving ideas — is what distinguishes sciences from non-sciences. The presence of the supernatural, for instance, is neither testable nor falsifiable.

To test a hypothesis, a researcher will conduct one or more **experiments** designed to eliminate, or disprove, the hypotheses. Each experiment will have one or more variables and one or more controls. A **variable** is any part of the experiment that can vary or change during the experiment. The **independent variable** is the variable that is manipulated throughout the course of the experiment. The **dependent variable,** or response variable is the variable by which we measure change in response to the independent variable. Ideally, all changes that we measure in the dependent variable are because of the manipulations we made to the independent variable. In most experiments, we will maintain one group that has had no experimental change made to it. This is the **control group.** It contains every feature of the **experimental group** except it is not given any manipulation. Therefore, if the results of the experimental group differ from the control group, the difference must be due to the hypothesized manipulation, rather than some outside factor. Look for the variables and controls in the examples that follow.

To test the hypothesis *"The classroom is warm because no one turned on the air conditioning,"* the student would find out if the air conditioning is on. If the air conditioning is turned on but does not work, there should be another reason, and this hypothesis should be rejected. To test the second hypothesis, the student could check if the lights in the classroom are functional. If so, there is no power failure and this hypothesis should be rejected. Each hypothesis should be tested by carrying out appropriate experiments. 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 1.2).** Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

The scientific method may seem too rigid and structured. It is important to keep in mind that, although scientists often follow this sequence, there is flexibility. 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. Notice, too, that the scientific method can be applied to solving problems that aren't necessarily scientific in nature.

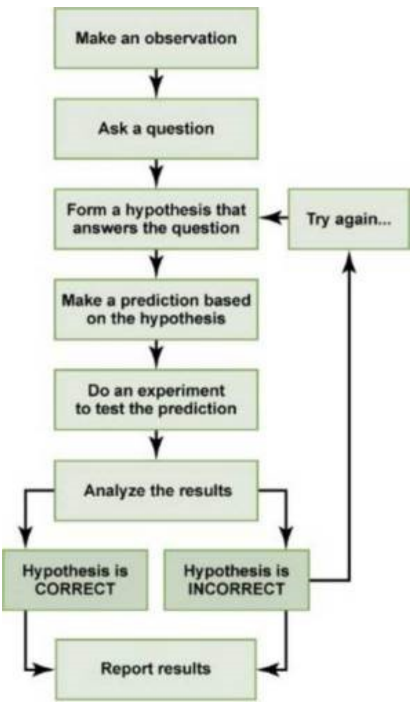


Figure 1.2 The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed.

Sustainability and sustainable

development

In 1983 the United Nations General Assembly passed a resolution that established the Special Commission on the Environmental Perspective to the Year 2000 and Beyond (http://www.un.org/documents/ga/res/38/a38r161.htm). Their charge was:

a. To propose long-term environmental strategies for achieving sustainable development to the year 2000 and beyond;

b. To recommend ways in which concern for the environment may be translated into greater co-operation among developing countries and between countries at different stages of economic and social development and lead to the achievement of common and mutually supportive objectives which take account of the interrelationships between people, resources, environment and development;

c. To consider ways and means by which the international community can deal more effectively with environmental concerns, in light of the other recommendations in its report;

d. To help define shared perceptions of long-term environmental issues and of the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community, taking into account the relevant resolutions of the session of a special character of the Governing Council in 1982.

Although the report did not technically invent the term **sustainability,** it was the first credible and widely disseminated study that used this term in the context of the global impacts of humans on the environment. Its main and often quoted definition refers to **sustainable development** as *development* *that meets the needs of the present without compromising the ability of future generations to meet their own needs*. The report uses the terms 'sustainable development', 'sustainable', and 'sustainability' interchangeably, emphasizing the connections among social equity, economic productivity, and environmental quality **(Figure 1.3).** This three-pronged approach to sustainability is now commonly referred to as the **triple bottom-line.** Preserving the environment for humans today and in the future is a responsibility of every generation and a long-term global goal. Sustainability and the triple bottom-line (meeting environmental, economic, and social goals simultaneously) require that we limit our environmental impact, while promoting economic well-being and social equity.

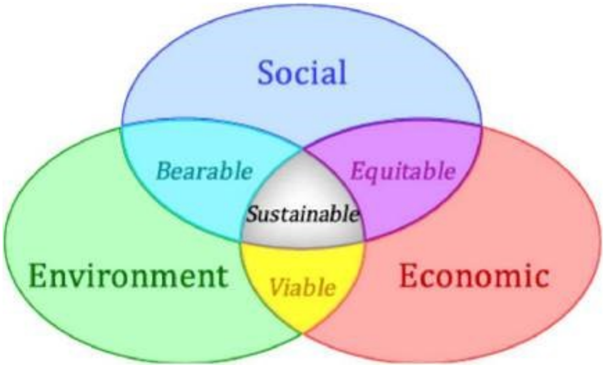


Figure 1.3. A depiction of the sustainability paradigm in terms of its three main components, showing various intersections among them. Source: International Union for the Conservation of Nature.

Examples of sustainable development include sustainable agriculture, which is agriculture that does not deplete soils faster than they form and does not destroy the biodiversity of the area. Sustainable farming and ranching do not reduce the amount of healthy soil, clean water, genetic diversity of crop plants and animals. Maintaining as much ecological

biodiversity as possible in the agro-ecosystem is essential to long-term crop and livestock production.

What is the environment worth to you?

The environment, and its benefits to individuals or groups, can be viewed and justified from multiple perspectives. A **utilitarian justification** for environmental conservation means that we should protect the environment because doing so provides a direct economic benefit to people. For example, someone might propose not developing Georgia's coastal salt marshes because the young of many commercial fishes live in salt marshes and the fishers will collapse without this habitat. An **ecological justification** for environmental conservation means that we should protect the environmental because doing so will protect both species that are beneficial to other as well as other species and an ecological justification for conservation acknowledges the many ecosystem services that we derive from healthy ecosystems. For example, we should protect Georgia's coastal salt marshes because salt marshes purify water, salt marshes are vital to the survival of many marine fishes and salt marshes protect our coasts from storm surges. An **aesthetic justification** for conservation acknowledges that many people enjoy the outdoors and do not want to live in a world without wilderness. One could also think of this as recreational, inspirational, or spiritual justification for conservation. For example, salt marshes are beautiful places and I always feel relaxed and calm when I am visiting one, therefore we should protect salt marches. And finally a **moral justification** represents the belief that various aspects of the environment have a right to exist and that it is our moral obligation to allow them to continue or help them persist. Someone who was arguing for conservation using a moral justification would say that it is wrong to destroy the coastal salt marshes.

The solution to most environmental problems requires a global perspective. Human population size has now reached a scale where the environmental impacts are global in scale and will require multilateral solutions. You will notice this theme continue as you move through this text. As you do so, keep in mind that the set of environmental, regulatory, and economic circumstances common in the United States are not constant throughout the world.

2. Principles of Ecology

JEAN BRAINARD

The Science of Ecology

Ecology is the study of how living things interact with each other and with their environment. It is a major branch of biology, but has areas of overlap with geography, geology, climatology, environmental science, and other sciences. This chapter introduces fundamental concepts in ecology related to organisms and the environment.

The Importance of Energy

Energy is defined as the ability move things, do work, or transfer heat, and comes in various forms, including light, heat, and electricity. There is Low-quality energy that comes in dispersed forms and high quality energy comes in condensed forms. Thermodynamics is the study of energy and the laws of thermodynamics, as you already learned about them, can be applied to energy flow in ecosystems. Remember: The first law of thermodynamics, or, the conservation of energy principle, states that energy may change from one form to another, but the total amount of energy will remain constant. That is to say that energy is not destroyed or created; it just changes form. For example, when wood is burned, the energy that was stored in the wood is not lost. It is given off as heat, smoke, and ash. The final amount of energy is the same just in new forms. The second law of thermodynamics is also important to environmental science and states that disorganization, or entropy, increases in natural systems through any spontaneous process. This means that as energy is used it is degraded to lower forms of energy.

These two laws are important to environmental science in the following ways:

1. First, and very important: we live in a closed system, the Earth's ecosphere. Nearly all of the organisms on Earth obtain their energy from the sun, and the sun composes the primary level of most ecosystem food chains, save a few deep-water thermal vents and some geyser bacteria. Since energy is neither created nor destroyed, as stated by the first law of thermodynamics, we can conclude that other than the sun's energy, the energy present is what we have to work with, including the food you live on
2. Second, when humans use non-renewable resources (such as oil) they are converting them into less-useful energy, as stated by the second law of thermodynamics. When those energy sources are depleted, they are gone. Use of these energy sources often also releases different elements back into the environment. For example, the combustion of oil releases carbon back into the air, and this offsets the carbon cycle (which you learn about). This helps contribute to climate change.

What these examples attempt to illustrate is that there are inputs and outputs to all energy types, and also benefits and costs to each kind. and each is controlled and limited within the laws of both ecology and thermodynamics.

Organisms and the Environment

Organisms are individual living things. Despite their tremendous diversity, all organisms have the same basic needs: energy and matter. These must be obtained from the environment. Therefore, organisms are not closed systems.

They depend on and are influenced by their environment. The environment includes two types of factors: abiotic and biotic.

1. Abiotic factors are the nonliving aspects of the environment. They include factors such as sunlight, soil, temperature, and water.
2. Biotic factors are the living aspects of the environment. They consist of other organisms, including members of the same and different species.

Levels of Organization

Ecologists study organisms and their environments at different levels. The most inclusive level is the biosphere. The biosphere consists of all the organisms on planet Earth and the areas where they live. It occurs in a very thin layer of the planet, extending from about 11,000 meters below sea level to 15,000 meters above sea level. An image of the biosphere is shown in Figure 2.1. Different colors on the map indicate the numbers of food-producing organisms in different parts of the biosphere. Ecological issues that might be investigated at the biosphere level include ocean pollution, air pollution, and global climate change.

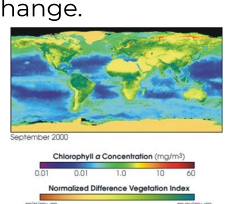


FIGURE 2.1 – Image of the biosphere

Ecologists also study organisms and their environments at the population level. A population consists of organisms of the same species that live in the same area and interact with one another. You will read more about populations in the Populations chapter. Important ecological issues at the population level include:

- rapid growth of the human population, which has led to overpopulation and environmental damage;

• rapid decline in populations of many nonhuman species, which has led to the extinction of numerous species.

Another level at which ecologists study organisms and their environments is the community level. A community consists of populations of different species that live in the same area and interact with one another. For example, populations of coyotes and rabbits might interact in a grassland community. Coyotes hunt down and eat rabbits
for food, so the two species have a predator-prey relationship. Ecological issues at the community level include how changes in the size of one population affect other populations. The Populations chapter discusses population interactions in communities in detail.

The Ecosystem

An ecosystem is a unit of nature and the focus of study in ecology. It consists of all the biotic and abiotic factors in an area and their interactions. Ecosystems can vary in size. A lake could be considered an ecosystem. So could a dead log on a forest floor. Both the lake and log contain a variety of species that interact with each other and with
abiotic factors. Another example of an ecosystem is pictured in Figure 2.2.

FIGURE 2.2 – Desert Ecosystem. What are some of the biotic and abiotic factors in this desert ecosystem?

When it comes to energy, ecosystems are not closed. They need constant inputs of energy. Most ecosystems get energy from sunlight. A small minority get energy from chemical compounds. Unlike energy, matter is not constantly added to ecosystems. Instead, it is recycled. Water and elements such as

carbon and nitrogen are used
over and over again.

Niche

One of the most important concepts associated with the ecosystem is the niche. A niche refers to the role of a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Look at
Figure 2.3. It shows pictures of birds that occupy different niches. Each species eats a different type of food and obtains the food in a different way.

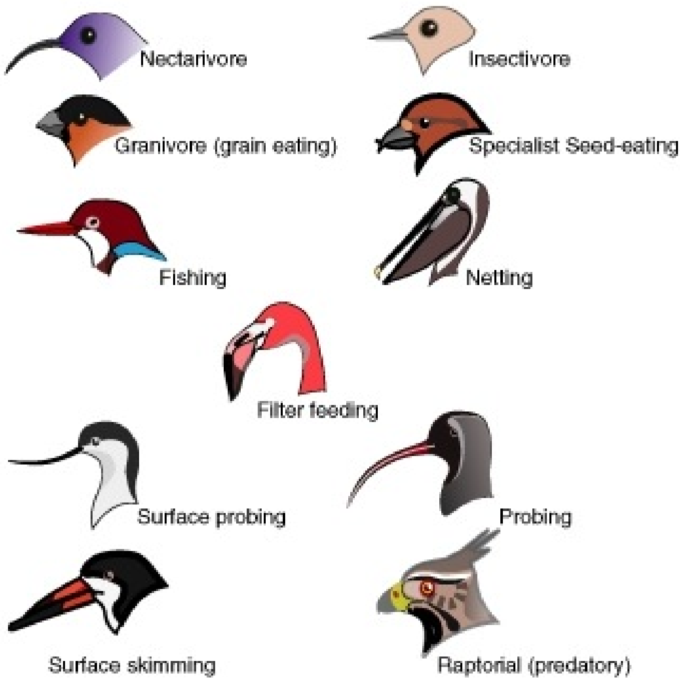


FIGURE 2.3 – Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example, the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard, tough grains.

Habitat

Another aspect of a species' niche is its habitat. The habitat is the physical environment in which a species lives and to which it is adapted. A habitat's features are determined mainly by abiotic factors such as temperature and rainfall. These factors also influence the traits of the organisms that live there.

Consider a habitat with very low temperatures. Mammals that live in the habitat must have insulation to help them stay warm. Otherwise, their body temperature will drop to a level that is too low for survival. Species that live in these habitats have evolved fur, blubber, and other traits that provide insulation in order for them to survive in the cold. Human destruction of habitats is the major factor causing other species to decrease and become endangered or go extinct. Small habitats can support only small populations of organisms. Small populations are more susceptible to being wiped out by catastrophic events from which a large population could bounce back. More than 1,200 species face extinction during the next century due mostly to habitat loss and climate change.

Flow of Energy: Producers and Consumers

Energy enters ecosystems in the form of sunlight or chemical compounds. Some organisms use this energy to make food. Other organisms get energy by eating the food.

Producers

Producers are organisms that produce food for themselves and other organisms. They use energy and simple inorganic molecules to make organic compounds. The stability of producers is vital to ecosystems because all organisms need organic molecules. Producers are also called autotrophs. There are two basic types of autotrophs:
photoautotrophs and chemoautotrophs.

1. Photoautotrophs use energy from sunlight to make food by photosynthesis. They include plants, algae, and certain bacteria (see Figure 2.6).
2. Chemoautotrophs use energy from chemical compounds

to make food by chemosynthesis. They include some bacteria and also archaea. Archaea are microorganisms that resemble bacteria.

Chemoautotrophs

In some places where life is found on Earth, there is not enough light to provide energy for photosynthesis. In these places, producers called chemoautotrophs use the energy stored in chemical compounds to make organic molecules by chemosynthesis. Chemosynthesis is the process by which carbon dioxide and water are converted to

carbohydrates. Instead of using energy from sunlight, chemoautotrophs use energy from the oxidation of inorganic compounds, such as hydrogen sulfide (H2S). Oxidation is an energy-releasing chemical reaction in which a molecule, atom, or ion loses electrons. Chemoautotrophs include bacteria called nitrifying bacteria, which live underground in soil. They oxidize nitrogen-containing compounds and change them to a form that plants can use. Chemoautotrophs also include archaea. Archaea are a domain of microorganisms that resemble bacteria. Most archaea live in extreme environments, such as around hydrothermal vents in the deep ocean. Hot water containing

hydrogen sulfide and other toxic substances escapes from the ocean floor at these vents, creating a hostile environment for most organisms. Near the vents, archaea cover the sea floor or live in or on the bodies of other organisms, such as tube worms. In these ecosystems, archaea use the toxic chemicals released from the vents to produce organic compounds. The organic compounds can then be used by other organisms, including tube worms. Archaea are able to sustain thriving communities, like the one shown in Figure 2.4, even in these hostile environments. Some chemosynthetic bacteria live around deep-ocean vents known as “black smokers.” Compounds such as

hydrogen sulfide, which flow out of the vents from Earth’s

interior, are used by the bacteria for energy to make food. Consumers that depend on these bacteria to produce food for them include giant tubeworms, like these pictured in Figure 2.5. Why do bacteria that live deep below the ocean's surface rely on chemical compounds instead of
sunlight for energy to make food?

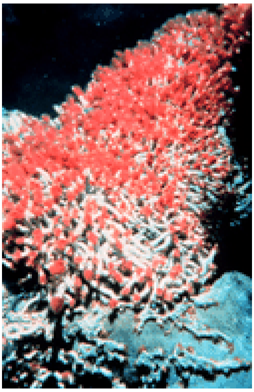


FIGURE 2.4 – Red tube worms, each containing millions of archaea microorganisms, grow in a cluster around a hydrothermal vent in the deep ocean floor.
Archaea produce food for themselves (and for the tube worms) by chemosynthesis.

FIGURE 2.5 – Tubeworms deep in the Gulf of Mexico get their energy from chemosynthetic bacteria. The bacteria actually live inside the worms.

Photoautotrophs

Phototautotrophs are organisms that use energy from sunlight to make food by photosynthesis. Photosynthesis is the process by which carbon dioxide and water are converted to glucose and oxygen, using sunlight for energy. Glucose, a carbohydrate, is an organic compound that can be used by autotrophs and other organisms for energy. As shown in Figure below, photoautotrophs include plants, algae, and certain bacteria.

Plants are the most important photoautotrophs in land-based, or terrestrial, ecosystems. There is great variation in the plant kingdom. Plants include organisms as different as trees, grasses, mosses, and ferns. Nonetheless, all plants

are eukaryotes that contain chloroplasts, the cellular "machinery" needed for photosynthesis. Algae are photoautotrophs found in most ecosystems, but they generally are more important in water-based, or aquatic, ecosystems. Like plants, algae are eukaryotes that contain chloroplasts for photosynthesis. Algae include single-celled eukaryotes, such as diatoms, as well as multicellular eukaryotes, such as seaweed. Photoautotrophic bacteria, called cyanobacteria, are also important producers in aquatic ecosystems. Cyanobacteria were formerly called blue-green algae, but they are now classified as bacteria. Other photosynthetic bacteria, including purple photosynthetic bacteria, are producers in terrestrial as well as aquatic ecosystems. Both cyanobacteria and algae make up phytoplankton. Phytoplankton refers to all the tiny photoautotrophs found on or near the surface of a body of water. Phytoplankton usually is the primary producer in aquatic ecosystems.

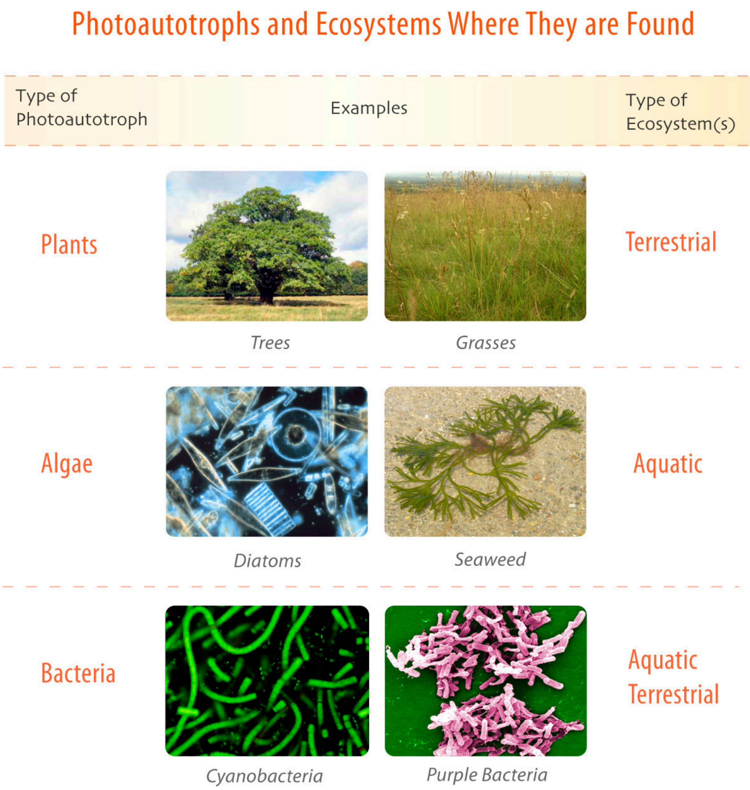


Figure 2.6 – Different types of photoautotrophs are important in different ecosystems.

Consumers

Consumers are organisms that depend on the producers (phototrophs or chemotrophs) organisms for food. They take in organic molecules by essentially "eating" other living things. They include all animals and fungi. (Fungi don't really "eat"; they absorb nutrients from other organisms.) They also include many bacteria and even a few plants, such as the pitcher plant in Figure below. Consumers are also called heterotrophs. Heterotrophs are classified by what they eat:

- **Herbivores** consume producers such as plants or algae. They are a necessary link between producers and other consumers. Examples include deer, rabbits, and mice.

- **Carnivores** consume animals. Examples include lions, polar bears, hawks, frogs, salmon, and spiders. Carnivores that are unable to digest plants and must eat only animals are called obligate carnivores. Other carnivores can digest plants but do not commonly eat them.
- **Omnivores** consume both plants and animals. They include humans, pigs, brown bears, gulls, crows, and some species of fish.

FIGURE 2.7 – Pitcher Plant. Virtually all plants are producers. This pitcher plant is an exception. It consumes insects. It traps them in a substance that digests
them and absorbs the nutrients.

Decomposers

When organisms die, they leave behind energy and matter in their remains. Decomposers break down the remains and other wastes and release simple inorganic molecules back to the environment. Producers can then use the molecules to make new organic compounds. The stability of decomposers is essential to every ecosystem. Decomposers are classified by the type of organic matter they break down:

- **Scavengers** consume the soft tissues of dead animals. Examples of scavengers include vultures, raccoons, and blowflies.
- **Detritivores** consume **detritus**—the dead leaves, animal feces, and other organic debris that collects on the soil or at the bottom of a body of water. On land, detritivores include earthworms, millipedes, and dung beetles (see **Figure** 2.8). In water, detritivores include “bottom feeders” such as sea cucumbers and catfish.

- **Saprotrophs** are the final step in decomposition. They feed on any remaining organic matter that is left after other decomposers do their work. Saprotrophs include fungi and single-celled protozoa. Fungi are the only organisms that can decompose wood.

FIGURE 2.8 – Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

Food Chains and Food Webs

Food chains and food webs are diagrams that represent feeding relationships. They show who eats whom. In this way, they model how energy and matter move through ecosystems.

Food Chains

A food chain represents a single pathway through which energy and matter flow through an ecosystem. An example is shown in Figure 2.9. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

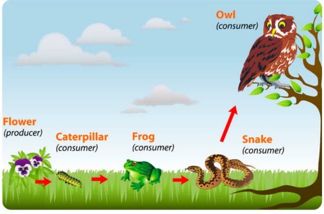


FIGURE 2.9 – This food chain includes producers and consumers. How could you add decomposers to the food chain?

Food Webs

A food web represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species. An example is shown in Figure 2.10.

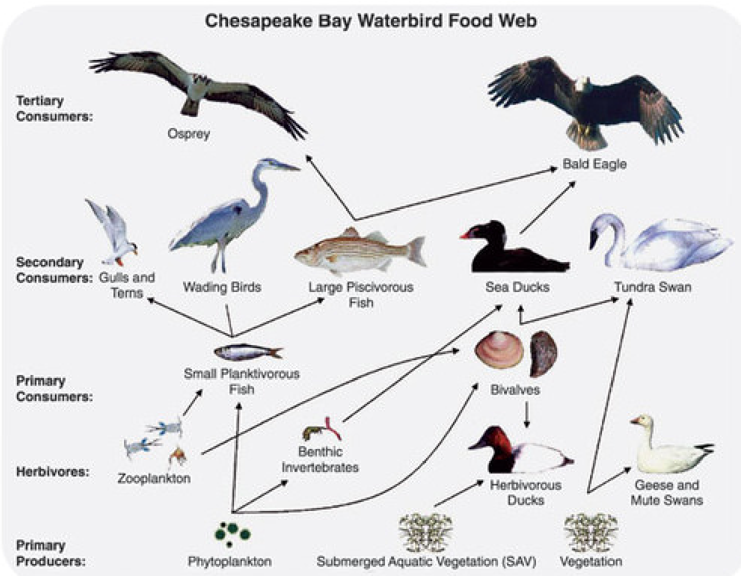


FIGURE 2.10 – Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

Trophic Levels

The feeding positions in a food chain or web are called trophic levels. The different trophic levels are defined in Table 1.1. Examples are also given in the table. All food chains and webs have at least two or three trophic levels. Generally, there are a maximum of four trophic levels.

Trophic Levels

Trophic Level	Where It Gets Food	Example
1st Trophic Level: Producer	Makes its own food	Plants make food
2nd Trophic Level: Primary Consumer	Consumes producers	Mice eat plant seeds
3rd Trophic Level: Secondary Consumer	Consumes primary consumers	Snakes eat mice
4th Trophic Level: Tertiary Consumer	Consumes secondary consumers	Hawks eat snakes

Many consumers feed at more than one trophic level. Humans, for example, are primary consumers when they eat plants such as vegetables. They are secondary consumers when they eat cows. They are tertiary consumers when they eat salmon.

Trophic Levels and Energy Transfer

The different feeding positions in a food chain or web are called trophic levels. The first trophic level consists of producers, the second of primary consumers, the third of secondary consumers, and so on. There usually are no more than four or five trophic levels in a food chain or web. Humans may fall into second, third, and fourth trophic levels of food chains or webs. They eat producers such as grain, primary consumers such as cows, and tertiary consumers such as salmon. Energy is passed up the food chain from one trophic level to the next. However, only about 10 percent of the total energy stored in organisms at one trophic level is actually transferred to organisms at the next trophic level. The rest of the energy is used for metabolic processes or lost to the environment as heat. As a result, less energy is available to organisms at each successive trophic level. This explains why there are rarely more than four or five trophic levels. The amount of energy at different trophic levels can be represented by an energy pyramid like the one in Figure 2.11.

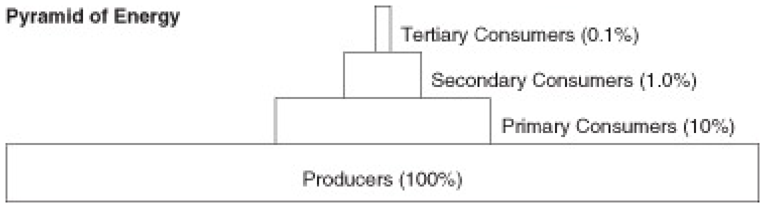


FIGURE 1.11 – This pyramid shows the total energy stored in organisms at each trophic level in an ecosystem. Starting with primary consumers, each trophic level in the food chain has only 10 percent of the energy of the level below it.

The pyramid makes it clear why there can be only a limited number of trophic levels in a food chain or web.

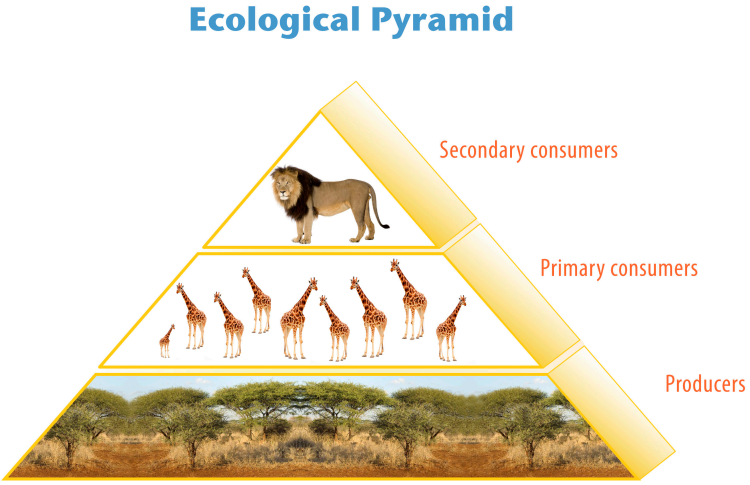


FIGURE 2.12 – Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1,000,000 kilocalories of energy. How much energy is available to primary consumers?

Community Interactions

Biomes as different as grasslands and estuaries share something extremely important. They have populations of interacting species. Moreover, species interact in the same basic ways in all biomes. For example, all biomes have some species that prey on other species for food. Species interactions are important biotic factors in ecological systems. The focus of study of species interactions is the community.

What Is a Community?

In ecology, a community is the biotic component of an ecosystem. It consists of populations of different species that live in the same area and interact with one another. Like abiotic factors, such as climate or water depth, species interactions in communities are important biotic factors in natural selection. The interactions help shape the evolution of the interacting species. Three major types of community interactions are predation, competition, and symbiosis.

Predation

Predation is a relationship in which members of one species (the predator) consume members of other species (the prey). The lions and cape buffalo in Figure 2.13 are classic examples of predators and prey. In addition to the lions, there is another predator in this figure. Can you find it? The other predator is the cape buffalo. Like the lion, it consumes prey species, in this case species of grasses. Predator-prey relationships account for most energy transfers in food chains and webs.

FIGURE 2.13 – An adult male lion and a lion cub feed on the carcass of a South African cape buffalo.

Types of Predators

The lions in Figure 2.13 are true predators. In true predation, the predator kills its prey. Some true predators, like lions, catch large prey and then dismember and chew the prey before eating it. Other true predators catch small prey and swallow it whole. For example, snakes swallow mice whole.

Some predators are not true predators because they do not kill their prey. Instead, they graze on their prey. In grazing, a predator eats part of its prey but rarely kills it. For example, deer graze on plants but do not usually kill them. Animals may also be "grazed" upon. For example, female mosquitoes suck tiny amounts of blood from
animals but do not harm them, although they can transmit disease.

Predation and Populations

True predators help control the size of prey populations. This is especially true when a predator preys on just one species. Generally, the predator-prey relationship keeps the population size of both species in balance. This is shown in Figure 2.14. Every change in population size of one species is followed by a corresponding change in the population size of the other species. Generally, predator-prey populations keep fluctuating in this way as long as there is no outside interference.

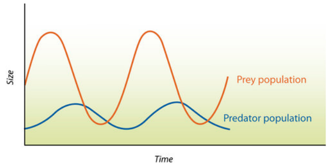


FIGURE 2.14

As the prey population increases, the predator population starts to rise. With more predators, the prey population starts to decrease, which, in turn, causes the
predator population to decline. This pattern keeps repeating. There is always a slight lag between changes in one population and changes in the other population.

Some predator species are known as keystone species, because they play such an important role in their community. Introduction or removal of a keystone species has a drastic effect on its prey population. This, in turn, affects populations of many other species in the community. For example, some sea star species are keystone species in
coral reef communities. The sea stars prey on mussels and sea urchins, which have no other natural predators. If sea stars are removed from a coral reef community, mussel and sea urchin populations would have explosive growth, which in turn would drive out most other species and destroy the reef community. Sometimes humans deliberately introduce predators into an area to control pests. This is called biological pest control. One of the earliest pests controlled in this way was a type of insect, called a scale insect. The scale insect was accidentally introduced into California from Australia in the late 1800s. It had no natural predators in California and was destroying the state's citrus trees. Then, its natural predator in Australia, a type of beetle, was introduced into California in an effort to control the scale insect. Within a few years, the insect was completely controlled by the predator. Unfortunately, biological pest

control does not always work this well. Pest populations often rebound after a period of decline.

Adaptations to Predation

Both predators and prey have adaptations to predation. Predator adaptations help them capture prey. Prey adaptations help them avoid predators. A common adaptation in both predator and prey species is camouflage, or disguise. One way of using camouflage is to blend in with the background. Several examples are shown in Figure 2.15.

Another way of using camouflage is to look like a different, more dangerous animal. Using appearance to "mimic" another animal is called mimicry. Figure 2.16 shows an example of mimicry. The moth in the figure has markings on its wings that look like the eyes of an owl. When a predator comes near, the moth suddenly displays the markings. This startles the predator and gives the moth time to fly away.

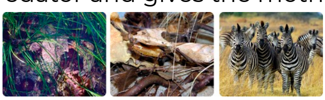


FIGURE 2.15 – Can you see the crab in the photo on the left? It is camouflaged with algae. The preying mantis in the middle photo looks just like the dead leaves in the background. The stripes on the zebras in the right photo blend the animals together, making it hard to see where one zebra ends and another begins.

Some prey species have adaptations that are the opposite of camouflage. They have bright colors or other highly noticeable traits that serve as a warning for their predators to stay away. For example, some of the most colorful butterflies are poisonous to birds, so birds have learned to avoid eating them. By being so colorful, the butterflies are more likely to be noticed—and avoided—by their predators.

FIGURE 2.16 – The moth on the left mimics the owl on the right.

Predation, Natural Selection, and Co-evolution

Adaptations to predation come about through natural selection (see the Evolution in Populations chapter). When a prey organism avoids a predator, it has higher fitness than members of the same species that were killed by the predator. The organism survives longer and may produce more offspring. As a result, traits that helped the prey organism avoid the predator gradually become more common in the prey population. Evolution of traits in the prey species leads to evolution of corresponding traits in the predator species. This is called co-evolution. In co-evolution, each species is an important factor in the natural selection of the other species. Predator-prey co-evolution is illustrated by rough-skinned newts and common garter snakes, both shown in Figure 2.17. Through natural selection, newts evolved the ability to produce a strong toxin. In response, garter snakes evolved the ability to resist the toxin, so they could still safely prey upon newts. Then, newts evolved the ability to produce higher levels of toxin. This was followed by garter snakes evolving resistance to the higher levels. In short, the predator-prey relationship led to an evolutionary "arms race," resulting in extremely high levels of toxin in newts.

FIGURE 2.17 – The rough-skinned newt on the left is highly toxic to other organisms. Common garter snakes, like the one on the right, have evolved resistance to the toxin.

Competition

Competition is a relationship between organisms that strive for the same limited resources. The resources might be food, nesting sites, or territory. Two different types of competition are intraspecific and interspecific competition.

- **Intraspecific competition** occurs between members of the same species. For example, two male birds of the same species might compete for mates in the same territory. Intraspecific competition is a necessary factor in natural selection. It leads to adaptive changes in a species through time (see the *Evolution in Populations* chapter).
- **Interspecific competition** occurs between members of different species. For example, two predator species might compete for the same prey. Interspecific competition takes place in communities of interacting species. It is the type of competition referred to in the rest of this section.

Interspecific Competition and Extinction

When populations of different species in a community depend on the same resources, there may not be enough resources to go around. If one species has a disadvantage, such as more predators, it may get fewer of the necessary resources. As a result, members of that species are less likely to survive, and the species will have a higher death
rate than the other species. Fewer offspring will be produced and the species may eventually die out in the area. In nature, interspecific competition has often led to the extinction of species. Many other extinctions have occurred when humans introduced new species into areas where they had no predators. For example, rabbits were introduced into Australia in the mid-1800s for sport hunting. Rabbits had no predators in Australia and quickly spread throughout the continent. Many species of Australian mammals could not successfully compete with rabbits and went extinct.

Interspecific Competition and Specialization

Another possible outcome of interspecific competition is the evolution of traits that create distinct differences among the competing species. Through natural selection, competing species can become more specialized. This allows them to live together without competing for the same resources. An

example is the anolis lizard. Many species of anolis live and prey on insects in tropical rainforests. Competition among the different species led to the evolution of specializations. Some anolis evolved specializations to prey on insects in leaf litter on the forest floor. Others evolved specializations to prey on insects on the branches of trees. This allowed the different species of anolis to
co-exist without competing.

Symbiotic Relationships

Symbiosis is a close association between two species in which at least one species benefits. For the other species, the outcome of the association may be positive, negative, or neutral. There are three basic types of symbiotic relationships: mutualism, commensalism, and parasitism.

Mutualism is a symbiotic relationship in which both species benefit. Lichen is a good example. A lichen is not a single organism but a fungus and an alga. The fungus absorbs water from air and minerals from rock or soil. The alga uses the water and minerals to make food for itself and the fungus. Another example involves goby fish and shrimp (see **Figure 2.17**). The nearly blind shrimp and the fish spend most of their time together. The shrimp maintains a burrow in the sand in which both the goby and the shrimp live. When a predator comes near, the fish touches the shrimp with its tail as a warning. Then, both fish and shrimp retreat to the burrow until the predator is gone. Each gains from this mutualistic relationship: the shrimp gets a warning of approaching danger, and the fish gets a safe home and a place to lay its eggs. Co-evolution often occurs in species involved in mutualistic relationships. Many examples are provided by flowering plants and the species that pollinate them. Plants have evolved flowers with traits that promote pollination by particular species. Pollinator species, in turn, have evolved traits that help them obtain pollen or nectar from certain species of flowers.

Figure 2.17: The multicolored shrimp in the front and the green goby fish behind it have a mutualistic relationship. The shrimp shares its burrow with the fish, and the fish warns the shrimp when predators are near. Both species benefit from the relationship.

Comensalism is a symbiotic relationship in which one species benefits while the other species is not affected. In commensalism, one animal typically uses another for a purpose other than food. For example, mites attach themselves to larger flying insects to get a "free ride," and hermit crabs use the shells of dead snails for shelter. Co-evolution explains some commensal relationships. An example is the human species and some of the species of bacteria that live inside humans. Through natural selection, many species of bacteria have evolved the ability to live inside the human body without harming it.

Parasitism is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed. Some parasites live on the surface of their host. Others live inside their host, entering through a break in the skin or in food or water. For example, roundworms are parasites of the human intestine. The worms produce huge numbers of eggs, which are passed in the host's feces to the environment. Other humans may be infected by swallowing the eggs in contaminated food or water. This usually happens only in places with poor sanitation. Some parasites eventually kill their host. However, most parasites do not. Parasitism in which the host is not killed is a successful way of life and very common in nature. About half of all animal species are parasitic in at least one stage of their lifecycle. Many plants and fungi are parasitic during some stages, as well. Not surprisingly, most animals are hosts to one or more parasites. Species in parastic relationships are likely to undergo co-evolution. Host species evolve defenses against parasites, and parasites evolve ways to evade host defenses. For example, many plants have evolved toxins that poison plant parasites such as fungi and bacteria. The microscopic parasite that causes malaria in humans has evolved a way to evade the human immune system. It hides out in the host's blood cells or liver where the immune system cannot find it.

3. Population Ecology

CARALYN ZEHNDER, KALINA MANOYLOV, SAMUEL MUTITI, CHRISTINE MUTITI, ALLISON VANDEVOORT, DONNA BENNETT

Population Ecology

Ecology is a sub-discipline of biology that studies the interactions between organisms and their environments. A group of interbreeding individuals (individuals of the same species) living and interacting in a given area at a given time is defined as a **population.** These individuals rely on the same resources and are influenced by the same environmental factors. **Population ecology,** therefore, is the study of how individuals of a particular species interact with their environment and change over time. The study of any population usually begins by determining how many individuals of a particular species exist, and how closely associated they are with each other. Within a particular habitat, a population can be characterized by its **population size** (N), defined by the total number of individuals, and its **population density,** the number of individuals of a particular species within a specific area or volume (units are number of individuals/unit area or unit volume). Population *size* and *density* are the two main characteristics used to describe a population. For example, larger populations may be more stable and able to persist better than smaller populations because of the greater amount of genetic variability, and their potential to adapt to the environment or to changes in the environment. On the other hand, a member of a population with low population density (more spread out in the habitat), might have more difficulty finding a mate to reproduce compared to a population of higher density. Other characteristics of a population include **dispersion** – the way individuals are spaced within the area; **age structure** – number of individuals in different age groups and; **sex ratio** – proportion of males to females; and growth – change in population size (increase or decrease) over time.

Populations change over time and space as individuals are born or immigrate (arrive from outside the population) into an area and others die or emigrate (depart from the population to another location). Populations grow and shrink and the age and gender composition also change through time and in response to changing environmental conditions. Some populations, for example trees in a mature forest, are relatively constant over time while others change rapidly. Using idealized models, population ecologists can predict how the size of a particular population will change over time under different conditions.

Exponential Growth

Charles Darwin, in his theory of natural selection, was greatly influenced by the English clergyman Thomas Malthus. Malthus published a book (An Essay on the Principle of Population) in 1798 stating that populations with unlimited natural resources grow very rapidly. According to the Malthus' model, once population size exceeds available resources, population growth decreases dramatically. This accelerating pattern of increasing population size is called **exponential growth,** meaning that the population is increasing by a fixed percentage each year. When plotted (visualized) on a graph showing how the population size increases over time, the result is a J-shaped curve **(Figure 3.1).** Each individual in the population reproduces by a certain amount (r) and as the population gets larger, there are more individuals reproducing by that same amount (the fixed percentage). In nature, exponential growth only occurs if there are no external limits.

One example of exponential growth is seen in bacteria. Bacteria are prokaryotes (organisms whose cells lack a nucleus and membrane-bound organelles) that reproduce by fission (each individual cell splits into two new cells). This process takes about an hour for many bacterial species. If 100 bacteria are placed in a large flask with an unlimited supply of nutrients (so the nutrients will not become depleted), after an hour, there is one round of division and each organism divides, resulting in 200 organisms – an increase of 100. In another hour, each of the 200 organisms divides, producing 400 – an increase of 200 organisms. After the third hour, there should be 800 bacteria in the flask – an increase of 400 organisms. After a day and 12 of these cycles, the population would have increased from 100 cells to more than 24,000 cells. When the population size, *N,* is plotted over time, a J-shaped growth curve is produced **(Figure 3.1).** This shows that the number of individuals added during each reproduction generation is accelerating – increasing at a faster rate.

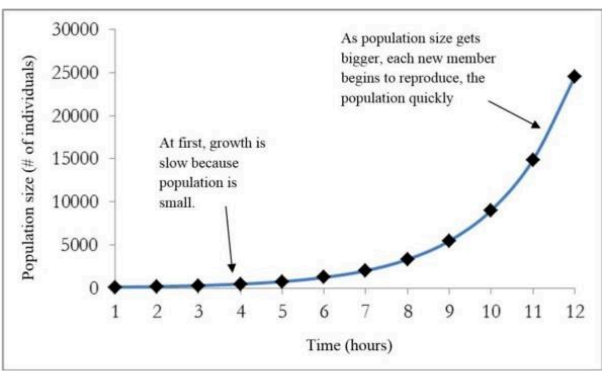


Figure 3.1: The “J” shaped curve of exponential growth for a hypothetical population of bacteria. The population starts out with 100 individuals and after 11 hours there are over 24,000 individuals. As time goes on and the population size increases,

the rate of increase also increases (each step up becomes bigger). In this figure “r” is positive.

Per capita rate of increase (r)

In exponential growth, the *population growth rate* **(G)** depends on population size *(N)* and the per capita rate of increase (r). In this model *r* does not change (fixed percentage) and change in population growth rate, **G,** is due to change in population size, ***N.*** As new individuals are added to the population, each of the new additions contribute to population growth at the same rate (r) as the individuals already in the population.

r = (birth rate + immigration rate) – (death rate and emigration rate).

If *r* is positive (> zero), the population is increasing in size; this means that the birth and immigration rates are greater than death and emigration.

If *r* is negative (< zero), the population is decreasing in size; this means that the birth and immigration rates are less than death and emigration rates.

If *r* is zero, then the population growth rate ***(G)*** is zero and population size is unchanging, a condition known as zero population growth. **“r”** varies depending on the type of organism, for example a population of bacteria would have a much higher **“r”** than an elephant population. In the exponential growth model r is multiplied by the population size, *N,* so population growth rate is largely influenced by N. This means that if two populations have the same per capita rate of increase *(r),* the population with a larger *N* will have a larger population growth rate than the one with a smaller *N.*

Logistic Growth

Exponential growth cannot continue forever because resources (food, water, shelter) will become limited. Exponential growth may occur in environments where there are few individuals and plentiful resources, but soon or later, the population gets large enough that individuals run out of vital resources such as food or living space, slowing the growth rate. When resources are limited, populations exhibit **logistic growth.** In logistic growth a population grows nearly exponentially at first when the population is small and resources are plentiful but growth rate slows down as the population size nears limit of the environment and resources begin to be in short supply and finally stabilizes (zero population growth rate) at the maximum population size that can be supported by the environment **(carrying capacity).** This results in a characteristic S-shaped growth curve **(Figure 3.2).** The mathematical function or logistic growth model is represented by the following equation:

Where, ***K*** is the *carrying capacity* – the maximum population size that a particular environment can sustain ("carry"). Notice that this model is similar to the exponential growth model except for the addition of the carrying capacity.

In the exponential growth model, population growth rate was mainly dependent on *N* so that each new individual added to the population contributed equally to its growth as those individuals previously in the population because per capita rate of increase is fixed. In the logistic growth model, individuals' contribution to population growth rate depends on the amount of resources available (K). As the number of individuals (N) in a population increases, fewer resources are available to each individual. As resources diminish, each individual on average, produces fewer offspring than when resources are plentiful, causing the birth rate of the population to decrease.

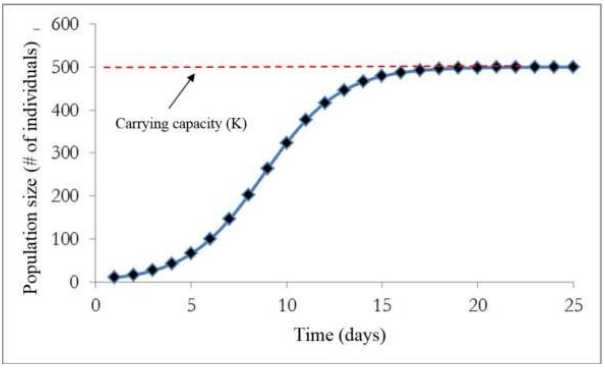


Figure 3.2: Shows logistic growth of a hypothetical bacteria population. The population starts out with 10 individuals and then reaches the carrying capacity of the habitat which is 500 individuals.

Yeast is a microscopic fungus, used to make bread and alcoholic beverages, that exhibits the classical S-shaped logistic growth curve when grown in a test tube **(Figure 3.3)**. Its growth levels off as the population depletes the nutrients that are necessary for its growth. In the real world, however, there are variations to this idealized curve. For example, a population of harbor seals may exceed the carrying capacity for a short time and then fall below the carrying capacity for a brief time period and as more resources become available, the population grows again **(Figure 3.4)**. This fluctuation in population size continues to occur as the population oscillates around its carrying capacity. Still, even with this oscillation, the logistic model is exhibited.

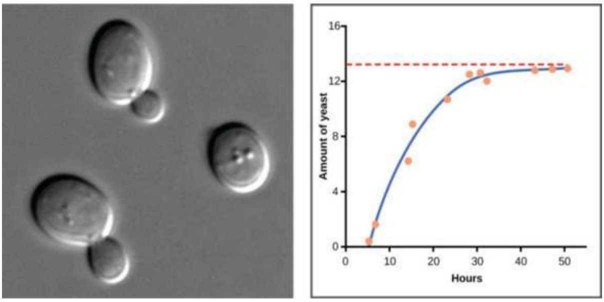


Figure 3.3: Graph showing amount of yeast versus time of growth in hours. The curve rises steeply, and then plateaus at the carrying capacity. Data points tightly follow the curve. The image is a micrograph (microscope image) of yeast cells

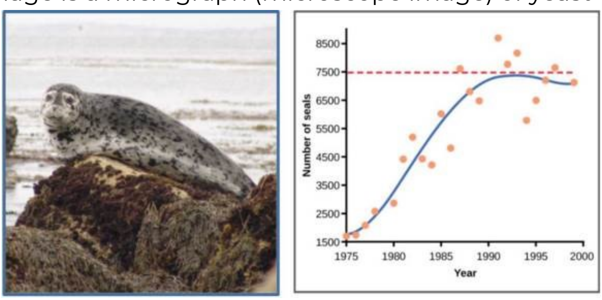


Figure 3.4: Graph showing the number of harbor seals versus time in years. The curve rises steeply then plateaus at the carrying capacity, but this time there is much more scatter in the data. A photo of a harbor seal is shown.

Factors limiting population growth

Recall previously that we defined density as the number of individuals per unit area. In nature, a population that is introduced to a new environment or is rebounding from a catastrophic decline in numbers may grow exponentially for a while because density is low and resources are not limiting. Eventually, one or more environmental factors will limit its population growth rate as the population size approaches the carrying capacity and density increases. Example: imagine that in an effort to preserve elk, a population of 20 individuals is introduced to a previously unoccupied island that's 200 km2 in size. The population density of elk on this island is 0.1 elk/km2 (or 10 km2 for each individual elk). As this population grows (depending on its per capita rate of increase), the number of individuals increases but the amount of space does not so density increases. Suppose that 10 years later, the elk population has grown to 800 individuals, density = 4 elk/ km2 (or 0.25 km2 for each individual). The population growth rate will be limited by various factors in the environment. For example, birth rates may decrease due to limited food or death rate increase due to rapid spread of disease as individuals encounter one another more often. This impact on birth and death rate in turn influences the per capita rate of increase and how the population size changes with changes in the environment. When birth and death rates of a population change as the density of the population changes, the rates are said to be density-dependent and the environmental factors that affect birth and death rates are known as **density-dependent factors.** In other cases, populations are held in check by factors that are not related to the density of the population and are called **density-independent factors** and influence population size regardless of population density. Conservation biologists want to understand both types because this helps them manage populations and prevent extinction or overpopulation.

The density of a population can enhance or diminish the impact of *density-dependent* factors. Most density-dependent factors are *biological* in nature (biotic), and include such things as predation, inter- and intraspecific competition for food and mates, accumulation of waste, and diseases such as those caused by parasites. Usually, higher population density results in higher death rates and lower birth rates. For example, as a population increases in size food becomes scarcer and some individuals will die from starvation meaning that the death rate from starvation increases as population size increases. Also as food becomes scarcer, birth rates decrease due to fewer available resources for the mother meaning that the birth rate decreases as population size increases. For density-dependent factors, there is a feedback loop between population density and the density-dependent factor.

Two examples of density-dependent regulation are shown in **Figure 3.5.** First one is showing results from a study focusing on the giant intestinal roundworm *(Ascaris lumbricoides),* a parasite that infects humans and other mammals. Denser populations of the parasite exhibited lower fecundity (number of eggs per female). One possible explanation for this is that females would be smaller in more dense populations because of limited resources and smaller females produce fewer eggs.

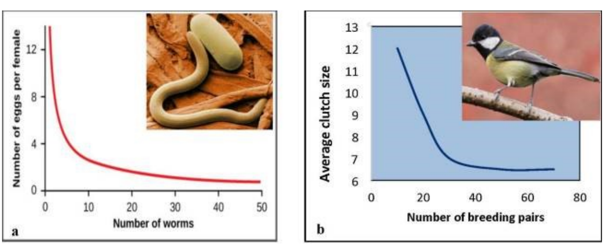


Figure 3.5: (a) Graph of number of eggs per female (fecundity), as a function of population size. In this population of roundworms, fecundity (number of eggs) decreases with population density, (b) Graph of clutch size (number of eggs per "litter") of the great tits bird as a function of population size (breeding pairs). Again, clutch size decreases as population density increases. (Photo credits: Worm image from Wikimedia commons, public domain image; bird image from Wikimedia commons, photo by Francis C. Franklin / CC-BY-SA-3.0)

Density-independent birth rates and death rates do NOT depend on population size; these factors are independent of, or not influenced by, population density. Many factors influence population size regardless of the population density, including weather extremes, natural disasters (earthquakes, hurricanes, tornadoes, tsunamis, etc.), pollution and other physical/abiotic factors. For example, an individual deer may be killed in a forest fire regardless of how many deer happen to be in the forest. The forest fire is not responding to deer population size. As the weather grows cooler in the winter, many insects die from the cold. The change in weather does not depend on whether there is a population size of 100 mosquitoes or 100,000 mosquitoes, most mosquitoes will die from the cold regardless of the population size and the weather will change irrespective of mosquito population density. Looking at the growth curve of such a population would show something like an exponential growth followed by a rapid decline rather than levelling off **(Figure 3.6)**.

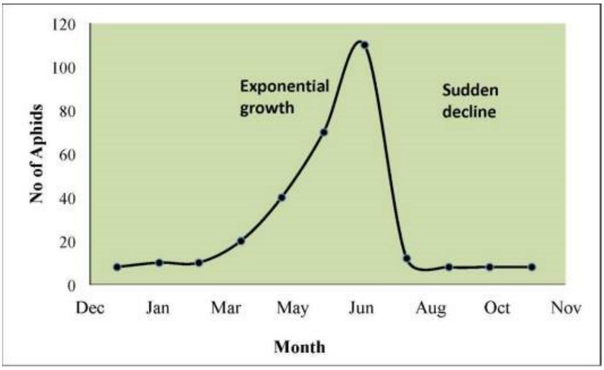


Figure 3.6: Weather change acting as a density-independent factor limiting aphid population growth. This insect undergoes exponential growth in the early spring and then rapidly die off when the weather turns hot and dry in the summer

In real-life situations, density-dependent and independent factors interact. For example, a devastating earthquake occurred in Haiti in 2010. This earthquake was a natural geologic event that caused a high human death toll from this *density-independent event*. Then there were high densities of people in refugee camps and the high density caused disease to spread quickly, representing a *density-dependent* death rate.

4. Air Pollution

JEAN BRAINARD

The Atmosphere

Water (1-4% near the Earth's surface) has so many unique properties (adhesion, surface tension, cohesion, capillary action, high heat capacity, high heat of vaporization…and more) that it is difficult for us to imagine any form of life on any planet which does not depend on it. As a major component of the hydrologic cycle, the atmosphere cleans and replenishes Earth's fresh water supply, and refills the lakes, rivers, and oceans habitats for life (**Figure 4.1**). The Earth's atmosphere thins but reaches away from its surface for 100 kilometers toward space; between about 15 and 35 km lies the Ozone Layer – just a few parts per million which shields life from the sun's damaging Ultra-Violet radiation. Earth's atmosphere appears ideal for life, and indeed, as far as we know it is the only planetary atmosphere which supports life.

Figure 4.1 A composite photo of satellite images shows Earth and its life-supporting waters and atmosphere.

As we noted in the History of Life chapter, the Earth's atmosphere has not always been this hospitable for life. Life itself is probably responsible for many dramatic changes, including the addition of oxygen by photosynthesis, and the subsequent production of ozone from accumulated oxygen. Changes in CO_2 levels, climate, and sea level have significantly altered conditions for life, even since the addition of oxygen some 2 billion years ago. On a daily time scale, dramatic changes take place:

- most organisms remove O_2 and add CO_2 through cellular respiration
- most autotrophs remove CO_2 and add O_2 through photosynthesis
- plants transpire vast quantities of water into the air
- precipitation returns it, through gentle rains or violent storms, to the Earth's surface

On a human time scale, the daily dynamics balance, and the atmosphere remains at equilibrium – an equilibrium upon which most life depends.

This is what the atmosphere looks like viewed edge on from space. The image is of a small cross-sectional area, note the small curvature of the surface, yet the atmosphere is a small part of the whole. Looking closely, you can see tall thunderstorm clouds silhouetted against an orange layer of atmospheric gases backlit by the sun just below the horizon. Above this layer is the clear blue of the stratosphere and the blackness of space. From NASA Space Shuttle Flight 6 on 4 April 1983.

Composition of the Atmosphere

The atmosphere is composed of 78.08% nitrogen and 20.95% oxygen with small amounts of other gases: 0.93% argon, 0.038% carbon dioxide, 0.002% neon, and yet smaller concentrations of helium, methane, krypton, and hydrogen. Both nitrogen and oxygen exist in large quantities only because of life on earth, especially life in the ocean.

It would seem that the composition of the atmosphere would be stratified with different chemical composition at different heights. In fact, mixing in the atmosphere causes the composition to be nearly uniform up to about 80 km.

Ozone is a very important trace gas in the atmosphere. It exits in two places:

1. In the stratosphere at heights around 20-30 km. This is good ozone. It protects all life on earth from dangerous solar ultraviolet radiation (energy).
2. Close to the surface due to pollution. It is produced from

nitrogen oxides and volatile carbon-based compounds when there is intense solar radiation (energy), above all in the spring and summer. This is bad ozone. It causes respiratory illness; it damages plants; and it attacks rubber.

Types of Air Pollutants

Despite the atmosphere's apparent vastness, human activities have significantly altered its equilibrium in ways which threaten its services for life. Chemical substances, particulate matter, and even biological materials cause **air pollution** if they modify the natural characteristics of the atmosphere. **Primary pollutants** are directly added to the atmosphere by processes such as fires or combustion of fossil fuels (**Figure** 4**.2**). Secondary pollutants, formed when primary pollutants interact with sunlight, air, or each other, can be equally damaging. The chlorine and bromine which threaten the Ozone Layer are **secondary pollutants**, formed when refrigerants and aerosols (primary pollutants) decompose in the stratosphere (**Figure** 4**.3**).

Figure 4.2 – Burning fossil fuels

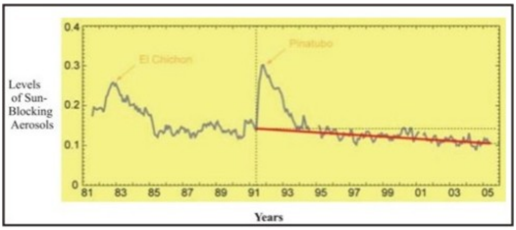


Figure 4.3 – Levels of sun-blocking aerosols declined from 1990 to the present. A corresponding return to pre-1960 levels of radiation suggests that pollution control measures in developed countries have counteracted Global Dimming. However, particulates are still a problem in developing countries, and could affect the entire global community again in the future. Aerosol increases in 1982 and 1991 are the result of eruptions of two volcanoes, El Chichon and Pinatubo.

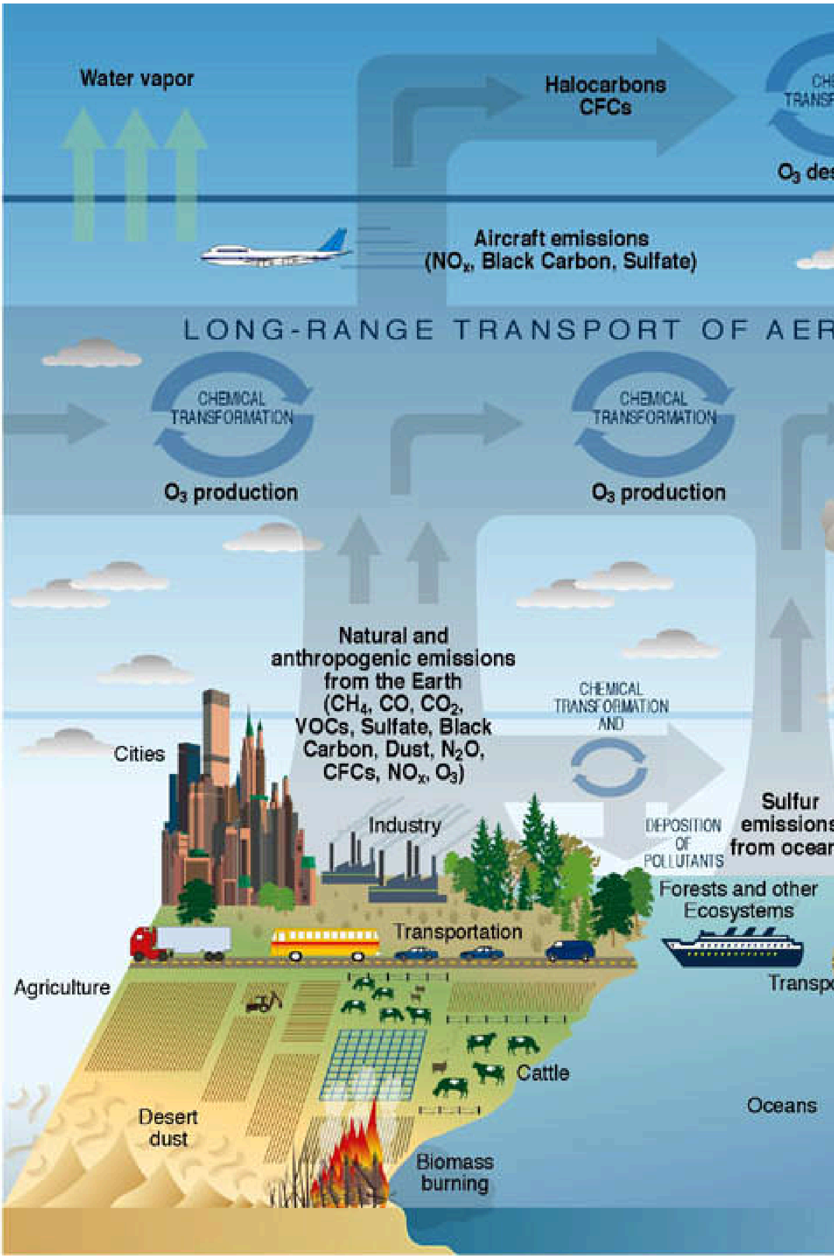
The majority of air pollutants can be traced to the burning of fossil fuels. We burn fuels in power plants to generate electricity, in factories to power machinery, in stoves and furnaces for heat, in airplanes, ships, trains, and motor vehicles for transportation, and in waste facilities to incinerate waste. Since long before fossil fuels powered the Industrial Revolution, we have burned wood for heat, fireplaces, and campfires and vegetation for agriculture and land management. The resulting primary and secondary pollutants and the problems to which they contribute are included in **Table 4.1** below.

Pollutant	Example/Major Source	Problem
Sulfur oxides (SO_X)	Coal-fired power plants	Acid Rain
Nitrogen oxides (NO_X)	Motor vehicle exhaust	Acid Rain
Carbon monoxide (CO)	Motor vehicle exhaust	Poisoning
Carbon dioxide (CO_2)	All fossil fuel burning	Global Warming
Particulate matter (smoke, dust)	Wood and coal burning	Respiratory disease, Global Dimming
Mercury	Coal-fired power plants, medical waste	Neurotoxicity
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

Beyond the burning of fossil fuels, other **anthropogenic** (human-caused) **sources** of air pollution are shown in **Table 4.2**.

Activity	Pollutant	Problem
Agriculture: Cattle Ranching Fertilizers Herbicides and Pesticides Erosion	Methane (CH_4) Ammonia (NH_3), Volatile Organic Chemicals(VOCs) Persistent Organic Pollutants(POP): DDT, PCBs, PAHs* Dust	Global Warming Toxicity, Global Warming Cancer Global Dimming
Industry (solvents, plastics) Refrigerants, Aerosols	VOCs, POPs CFCs	Cancer, Global Warming Ozone Depletion
Nuclear power and defense	Radioactive waste	Cancer
Landfills	Methane (CH_4)	Global Warming
Mining	Asbestos	Respiratory problems
Biological Warfare	Microorganisms	Infectious Disease
Indoor Living	CO, VOCs, asbestos, dust, mites, molds, particulates	Indoor air pollution

- DDT = an organic pesticide; PCB = poly-chlorinated biphenyls, used as coolants and insulators; DDT and most PCBs are now banned at least in the U.S., but persist in the environment; PAHs = polycyclic aromatic hydrocarbons – products of burning fossil fuels, many linked to health problems



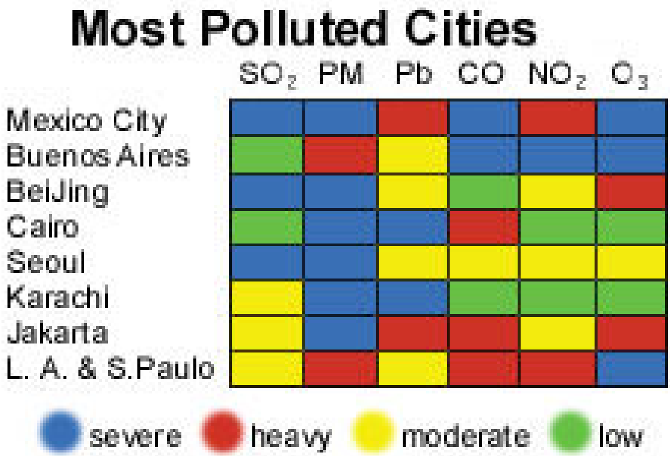
processes contribute to atmospheric pollution and trace gases. Click on imag
Science Program, Final Report July 2003: Chapter 3 Atmospheric Compositio

http://oceanworld.tamu.edu/resources/environment-book/Images/Atmosphere_composition_diagram.jpg

The important sources of atmospheric pollution on a global or regional scale are:

1. Automobiles. According to the U.S. Environmental Protection Agency (EPA), driving a car is the single most polluting thing that most of us do. Motor vehicles emit millions of tons of pollutants into the air each year. In many urban areas, motor vehicles are the single largest contributor to ground-level ozone, a major component of smog. The primary pollutants produced by automobiles are:
    1. Hydrocarbons. They come from the evaporation of fuel, especially on hot days, leaking fluids, and during refueling at gas stations.
    2. Nitrogen oxides. Produced by high heat during the burning of fuel.
    3. Carbon monoxide. Produced by the incomplete burning of fuel.

    Modern automobiles pollute much less than older models thanks to emission controls including catalytic converters. But the number of cars is so large, and they are driven so much, they are still major sources of pollution.
2. Urban activity. The world's population is concentrated more and more in mega cities, with five urban areas having more than 20 million people: Tokyo, Japan (34,997,000); Mexico City (22,800,000); Seoul, South Korea (22,300,000); New York (21,900,000); and São Paulo, Brazil (20,200,000). Urban air pollution is now common in all large cities, worse on some days, better on others, but never gone.



From Air Pollu
Salzburg University Sound and Video Studio. It is caused not only by emissions
lawnmowers (operating a lawn mower for one hour produces as much pollutio
by fumes from drying paint, charcoal fires (grills), and dry cleaners.

A huge traffic jam backs up the streets in Bangkok. High population density ir
image for a zoom. From Patagonia.

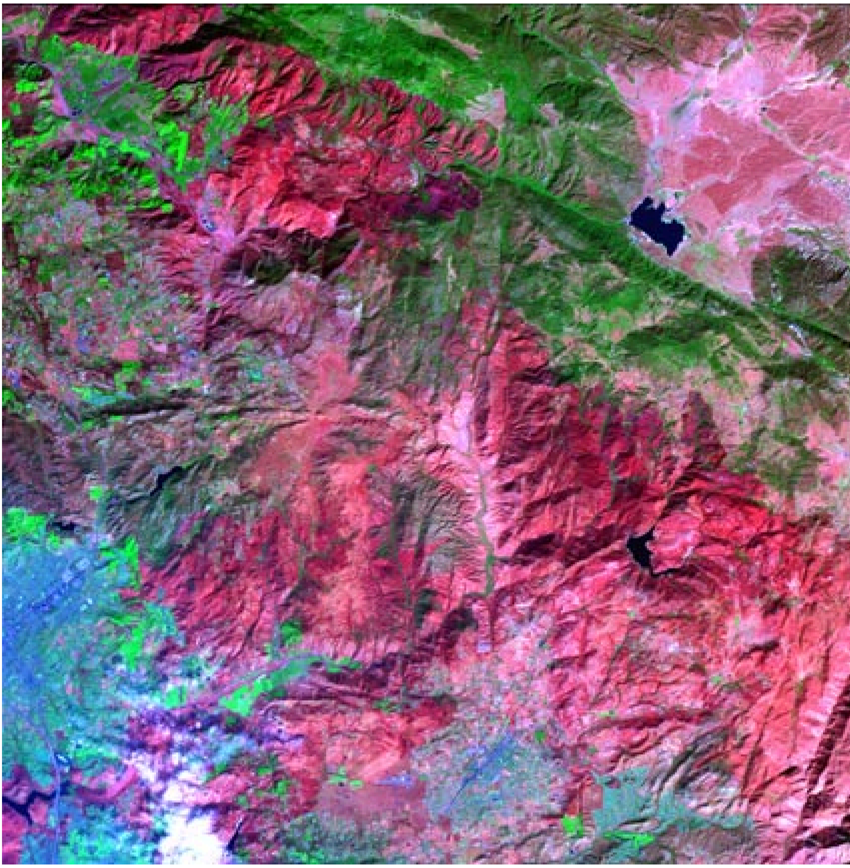
Urban activity leads to photochemical smog in many areas such as Los Angeles, Houston, Mexico City, and London, the archetype of a smoggy city (The term smog was coined by Dr. Henry Antoine Des Voeux in 1905, when he combined the words smoke and fog). In London, the smoke came from the burning of coal to heat thousands of houses. The London smog began in the middle ages, and extreme smog events led to periodic attempts to reduce air pollution. The great smog of 5-9 December 1952 killed more than 4,700 people during the event, and led to an additional 8,000 deaths in the year following the event. During the event, visibility was reduced to 20 m over an area of 20 by 40 km (Boubel et al, 1994) and deaths reached 900 per day. To ensure that such an event would never happen again, parliament passed the UK Clean Air Act of 1956. Photochemical smog is formed when sunlight acts on volatile carbon-based molecules and nitrous oxides trapped below inversions above cities. The sunlight powers chemical reaction that form harmful pollutants such as tropospheric ozone, aldehydes, and peroxyacyl nitrates (PAN). Here is an outline of some important chemical reactions leading to smog: The high temperature in automobile and diesel engines converts nitrogen gas to nitrous oxide. N_2 + O_2 ——> 2 NO (nitric oxide) In the atmosphere, nitric oxide is converted to nitrogen dioxide NO_2, a brown gas which gives smog its characteristic color. 2 NO + O_2 ———> 2 NO_2 When nitrogen dioxide concentrations are high, sunlight leads to the formation of ozone. NO_2 + sunlight ————-> NO + O O + O_2 ————> O_3. NO_2 + O_2 + hydrocarbons + sunlight ————-> CH_3CO-OO-NO_2 (peroxyacetylnitrate).

Angeles smog on 29 January 2004. The top of the inversion layer is easily seen a
backdrop of distant mountains. Hilltops above the layer are visible at great dist
areas below the layer are obscured. Click on image for a zoom. Photo by Alan C
Middlesbrough, England.


This
Angeles looks like from the ground, a thick brown or slightly orange haze with
scene, the inversion is below the top of the highest buildings. The exhaust from
driven in the morning rush hour is trapped below this level. Click on image for
article Choking on Air.

http://oceanworld.tamu.edu/resources/environment-book/Images/LA-smog-2.jpg

3. Agricultural burning.
4. Forest fires.



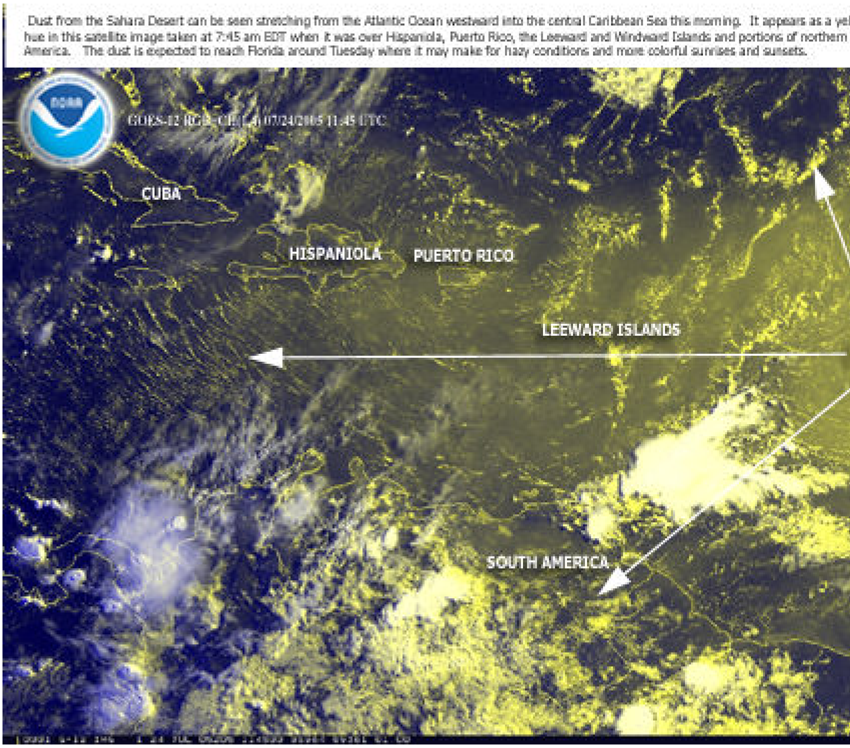
Wildfires and smoke on 23 October 2007 in southern California. The fires bur the size of Rhode Island. The smoke from the fires is clearly visible over the Pac spots mark the location of the fires. Click on image for zoom. From NASA Califo the NOAA site: Operational Significant Event Imagery. NOAA issues daily Fire P forest fires in North America, and information of **Fire Events** worldwide.

5. Industrial activity Smelters, steel mills, oil refineries and chemical plants, paper mills, manufacturing plants, and power plants, especially coal-fired plants are the major sources. But even relatively clean industries such as semiconductor fabrication plants, which make computer

chips, also contribute. Many of the worst polluters were in the format Soviet Union. Fortunately, industrial emissions are being greatly reduced as nations become richer.

Lenin Steel mill, Magnitogorsk, 1991. From Monroe Gallery of Photography, pho
Sherbell. Dust storms. Strong winds blowing across desert regions lift dust hig
The higher-level winds then carry dust great distances. The Sahara, the Aral Se
notorious sources.

6. Dust Storms (see the chapter titled Land Degredation and Desertification for more detalis).



Dust blown from the Sahara across the Atlantic on 24 July 2005. Dust is colore
yellow-brown in the image. From NOAA Dust Storm site. NASA has a catalog of
of dust storms.

Many pollutants travel indoors.

Pollutants from the air travel into building materials, furniture, carpeting, paints and varnishes, contributing to indoor air pollution. In 2002, the World Health Organization estimated that 2.4 million people die each year as a consequence of air pollution – more than are killed in automobile accidents. Respiratory and cardiovascular problems are the most common health effects of air pollution, but accidents which release airborne poisons (the nuclear power plant at Chernobyl, the Union Carbide explosion in Bhopal, and the "Great Smog of 1952" over London) have killed many people – and undoubtedly other animals – with acute exposure to radiation or toxic chemicals.

If you study the problems caused by air pollution (third column in the tables, above), you will note that beyond human health, air pollution affects entire **ecosystems**, worldwide. **Acid Rain, Ozone Depletion**, and **Climate Change** are widespread and well-recognized global concerns, so we will explore them in detail in independent sections of this lesson, – and an entire lesson on Climate Change. Effects of toxins, which poison wildlife and plants as well as humans, were addressed in discussions of soil and water pollution in the last chapter. Before we move on to the "Big Three," let's take a brief look at the problems caused by particulates and aerosols, since these are unique pollutants of air, rather than soil or water.

Global Dimming

"Global dimming" refers to a reduction in the amount of radiation reaching the Earth's surface. Scientists observed a drop of roughly 4% between 1960 and 1990, and attributed it to particulates and aerosols (in terms of air pollution, **aerosols** are airborne solid particles or liquid droplets). These pollutants absorb solar energy and reflect sunlight back into space. The consequences for life are many:

- Less sunlight means less photosynthesis.
- Less photosynthesis means less food for all trophic levels.
- Less sunlight means less energy to drive evaporation and the hydrologic cycle.
- Less sunlight means cooler ocean temperatures, which may lead to changes in rainfall, drought and famine.
- Less sunlight may have cooled the planet, masking the

effects of Global Warming.

Recent measurements of sunlight-absorbing particulates show a decline since 1990, which corresponds to a return to normal levels of radiation. These data suggest that Clean Air legislation enacted by developed nations may have improved air quality and prevented most of the above effects, at least for now. Two caveats remain:

1. If “Global Dimming” did indeed mask Global Warming for 30 years, predictions about future climate change may be too conservative. Keep this in mind when we address Global Warming in the next lesson.
2. Population growth and industrialization of developing countries continues to increase levels of **pollution**.

Massive waves of pollution from Asian industry have blown across the Pacific by prevailing winds (**Figure 4.4**). On some days, atmospheric physicists at the Scripps Institution of Oceanography have traced nearly one-third of the air over Los Angeles and San Francisco directly to Asian sources. The waves are made of dust from Asian deserts combined with pollution from increasing industrialization, making the level of particulates and aerosols in Beijing, for example, reach levels 7 times World Health Organization standards. Scientists estimate that the clouds may be blocking 10% of the sunlight over the Pacific. By seeding clouds, the aerosols and particulates may be intensifying storms. In addition to direct effects on the global atmosphere (such waves can circle the Earth in three weeks), these pollution clouds can, as we stated above, mask Global Warming.

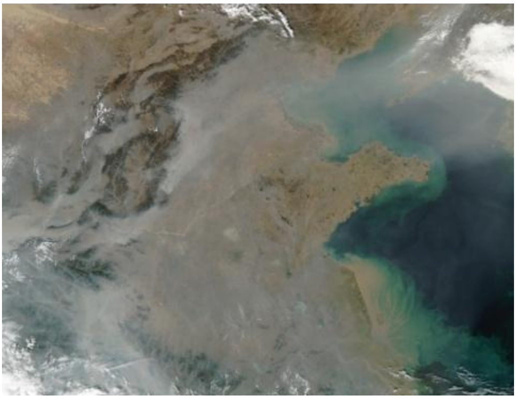


Figure 4.4 – A cloud of smoke and haze covers this region of China from Beijing (top center) to the Yangtze River (bottom right). At the top right, pollution is blowing eastward toward Korea and the Pacific Ocean. Aerosol pollution with large amounts of soot (carbon particles) is changing precipitation and temperatures over China. Some scientists believe that these changes help to explain increasing floods and droughts.

Light Pollution

One additional topic relates to atmospheric change. **Light pollution** (**Figure 4.5**) results from humans' production of light in amounts which are annoying, wasteful, or harmful. Light is essential for safety and culture in industrial societies, but reduction in wasteful excess could mitigate its own harmful effects, as well as the amounts of fossil fuel used to generate it. Astronomers – both amateur and professional – find light interferes with their observations of the night skies. Some studies show that artificial spectra and excessive light exposure has harmful effects on human health. Life evolved in response to natural cycles and natural spectra of light and dark, so it is not surprising that our changes in both of those might affect us and other forms of life. Light pollution can affect animal navigation and migration and predator/prey interactions. Because many birds migrate by night, Toronto, Canada has initiated a program to turn out lights at night during spring and fall migration seasons. Light may interfere with sea turtle egg-laying and hatching, because both happen on coasts at nighttime. The behavior of nocturnal animals from owls to moths can be changed by light, and night-blooming flowers can be affected directly or through disruption of pollination. Zooplankton normally show daily vertical migration, and some data suggests that changes in this behavior can lead to **algal blooms**.

Figure 4.5 – When light produced by humans becomes annoying, wasteful, or harmful, it is considered light pollution. This composite satellite image of Earth at night shows that light is concentrated in urban

Solutions to problems caused by light pollution include

- reducing use
- changing fixtures to direct light more efficiently and less harmfully
- changing the spectra of light released
- changing patterns of lighting to increase efficiency and reduce harmful effects

Acid Rain

Acid rain is a common name for the deposition of acidic material from the atmosphere either as:

1. Wet deposition of acid in precipitation (rain, snow, or fog); or
2. Dry deposition of acidic material on dust, smoke, or other aerosols (small, microscopic particles in the air).

Acid rain was a major problem in Europe and the USA in the last few decades of the 20th century. Strong emission control laws have greatly reduced the problem in these areas. However, acid rain continues to be a major problem in some developing countries, especially China.

Here both types of deposition will be covered.

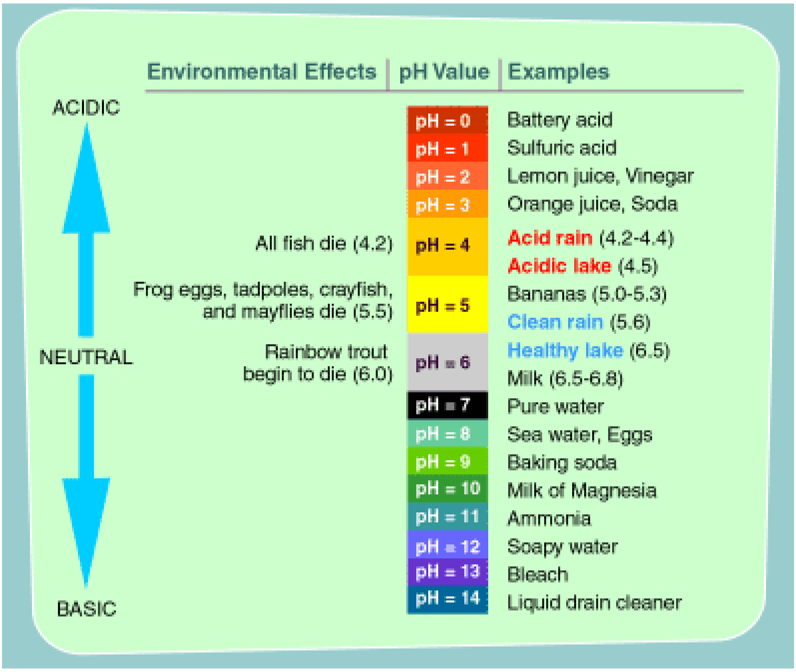
Do you remember the pH scale? Its range is 0-14, and 7 is neutral – the pH of pure water. You've probably measured the pH of various liquids such as vinegar and lemon juice, but do you know how important even very small changes in pH are for life? Your body maintains the pH of your blood between 7.35 and 7.45, and death results if blood pH falls below 6.8 or rises above 8.0. All life relies on relatively narrow ranges of pH, because protein structure and function is extremely sensitive to changes in concentrations of hydrogen ions. An important pollution problem which affects the pH of Earth's environments is **Acid Rain** (**Figure** below).

Acidity of precipitation is measured in pH units, where

$$pH \approx -\log[H^+]$$

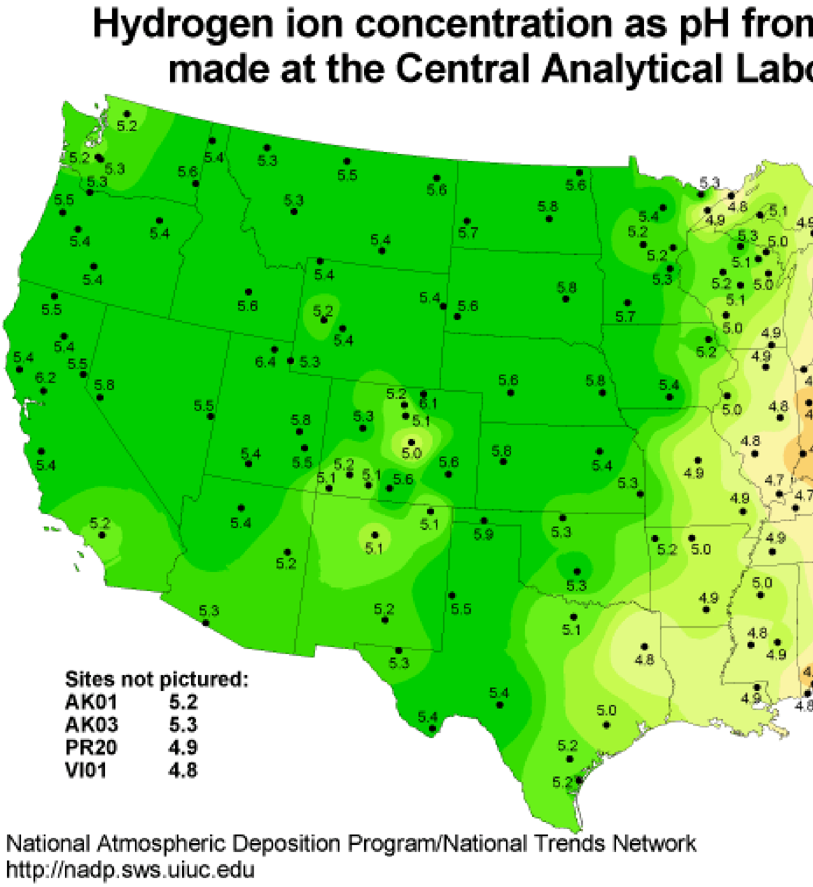
where H^+ is the dissolved hydrogen ion concentration in a weak solution in water. The lower the pH the more acidic the precipitation, the higher the pH the more basic the precipitation. Pure water water has a pH of 7.0, and pure rain has a ph of 5.6 because carbon dioxide dissolved in water forms a weak acid, carbonic acid, H_2CO_3.

$$H_2O + CO_2 \rightarrow H_2CO_3$$



pH scale from Environmental Protection Agency, pH Scale.

The pH of precipitation from very polluted air can be less than 2 in extreme cases. Mostly, the pH of precipitation ranges from 4.4 to 5.8.



Acidity of precipitation measured by the National Atmospheric Deposition
most acidic downwind of the large concentration of power plants in the Ohio

Sources of Acid rain

The acidic materials come from sulfur dioxide (SO_2), ammonia (NH_3), nitrogen oxides (NOx) and acidic particles emitted into the atmosphere by burning of fossil fuels in power plants and cars. In the United States, roughly 2/3 of all SO_2 and 1/4 of all

NOx come from burning of fossil fuels, especially coal, in electric power plants.

Left: Coal-fired power plant
quantities of acid pollutants into the atmosphere, although the volume of pollutant
decreasing as scrubbers that remove pollutants from exhaust gases have become r
The image shows exhaust from the American Electric Power's Gen. James M. Gavin
Gallia County, in the Ohio Valley. It is one of the largest coal-fired power plants in Oh
visible exhaust is condensed vapor, but the brownish haze includes acids. From Ohi
Beacon Journal, article Ohio EPA cites area for soot problems. Right: Scrubber at ba
Power's Bowen Plant removes 95% of the sulfur dioxide in the plant's exhaust gas. C
bring up a diagram of how a scrubber works from Scrubber freshens smokestack b
Staff Writer for the News Observer. From Rome-News Tribune.

Rain, snow, fog, dew, and even dry particles which have an unusually low pH are commonly considered together as **Acid Rain**, although more accurate terms would be acid precipitation or acid deposition. You will remember that a pH below 7 is acidic, and the range between 7 and 14 is basic. Natural precipitation has a slightly acidic pH, usually about 5, mostly because CO_2, which forms 0.04% of the atmosphere, reacts with water to form carbonic acid:

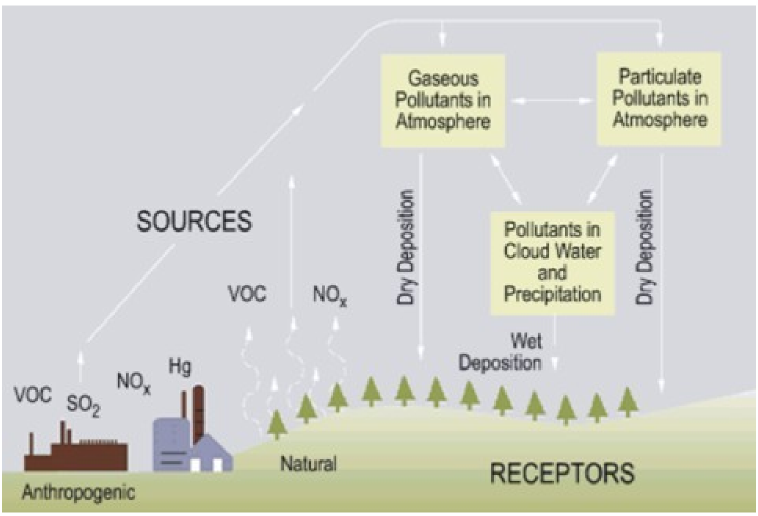
CO_2	$+ H_2O$	$\rightleftharpoons H_2CO_3$	$\rightleftharpoons HCO_3^-$	$+ H^+$
carbon dioxide	water	carbonic Acid	bicarbonate	hydrogen ion

This natural chemical reaction is actually quite similar to the formation of acid rain, except that levels of the gases which replace carbon dioxide are not normally significant in the atmosphere. The most common acid-forming pollutant gases are oxides of nitrogen and sulfur released by the burning of fossil fuels. Because burning may result in several different oxides, the gases are often referred to as "NO_X and SO_X." This may sound rather affectionate, but it's more accurate to think of it as obNOXious! Whereas the carbonic acid formed by carbon dioxide is a relatively weak acid, the nitric and sulfuric acids formed by NO_X and SO_X are strong acids, which ionize much more readily and therefore cause more damage. The reactions given below slightly simplify the chemistry (in part because NO_X and SO_X are complex mixtures of gases), but should help you see the acidic results of an atmospheric mixture of water and these gases.

NO_2	$+ OH^-$	$\rightarrow HNO_3$	$\rightleftharpoons NO_3^-$	$+ H^+$
nitrogen dioxide	hydroxide ion (from water)	nitric Acid	nitrate	hydrogen ion

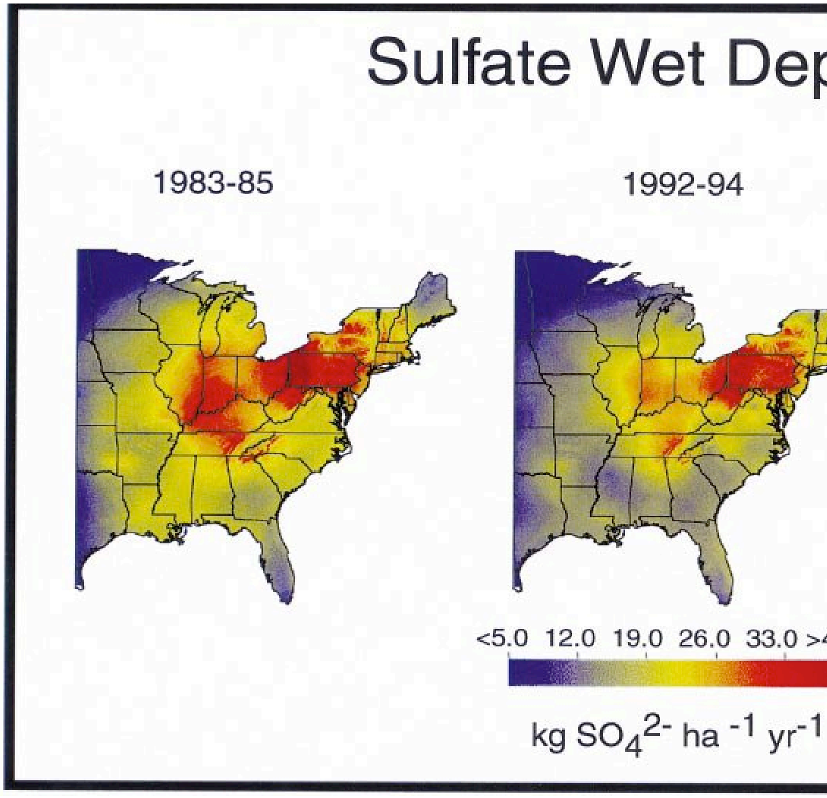
SO_3	$+ H_2O$	$\rightarrow H_2SO_4$	$\rightleftharpoons SO_4^{-2}$	$+ 2H^+$
sulfur trioxide	water	sulfuric acid	sulfate	hydrogen ions

Nitrogen and sulfur oxides have always been produced in nature by volcanoes and wildfires and by biological processes in wetlands, oceans, and even on land. However, these natural levels are either limited in time or amount; they account for the slightly acidic pH of “normal” rain. Levels of these gases have risen dramatically since the Industrial Revolution began; scientists have reported pH levels lower than 2.4 in precipitation in industrialized areas. Generation of electricity by burning coal, industry, and automobile exhaust are the primary sources of NO_X an SO_X. Coal is the primary source of sulfur oxides, and automobile exhaust is a major source of nitrogen oxides.



Acid rain thus 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. – What is Acid Rain, EPA.

Most acid rain falls downwind of power plants. In the USA, many are located in the mid-west, and acid rain is common there and throughout the east coast. As power plant emissions are increasingly regulated, the amount of acid rainfall has decreased. Total annual emissions of SO_2 in the USA dropped from 28.8 × 10^6 metric tons in 1978 to 17.8 × 10^6 metric tons in 1998.



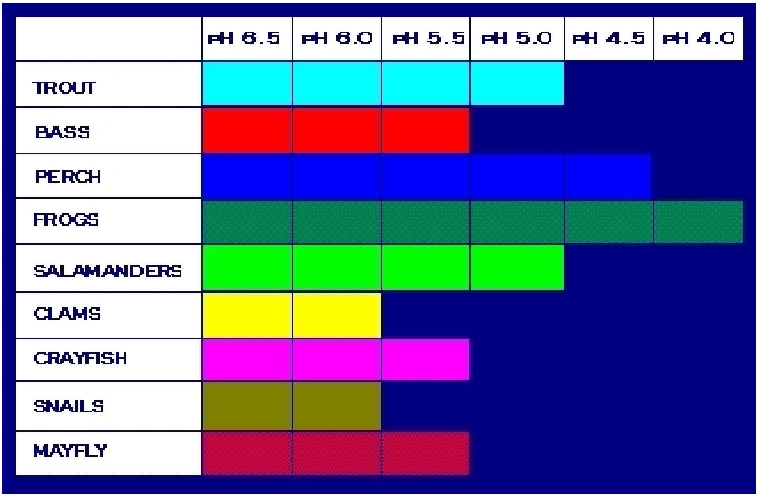
Acid rain deposition in the USA from 1983 through 1997. From: Driscoll (2001).

Affects on Vegetation and Animals

Because most life requires relatively narrow pH ranges near neutral, the effects of acid rain can be devastating. In soils, lowered pH levels can kill microorganisms directly, altering decomposition rates, nutrient cycles, and soil fertility. A secondary effect of increased acidity is the leaching of nutrients, minerals, and toxic metals such as aluminum and lead from soils and bedrock. Depletion of nutrients and mobilization of toxins weakens trees and other plants, especially at higher altitudes where higher precipitation and acid fog damage leaves and needles, as well (**Figure** below).

A mountain forest in the Czech Republic shows effects attributed to acid rain. At higher altitudes, effects on soils combine with direct effects on foliage of increased precipitation and fog.

The flow of acid rain through watersheds increases acidity, nutrients, and toxins in aquatic ecosystems. Fish and insects are sensitive to changes in pH, although different species can tolerate different levels of acidity (**Figure** below). Food chain disruption can compound even slight changes in pH; for example, acid-sensitive mayflies provide food for less-sensitive frogs.



Aquatic species show varying sensitivity to pH levels. Colored bars show survival ranges. Trout are more sensitive to increasing acidity than frogs, but mayflies, which frogs consume, are even more sensitive. Consequently, changes in a lake

In some regions, especially regions where granite is close to the surface and where soils have been degraded by logging and forest fires, the soil has little ability to neutralize the acid. In these regions, acid deposition depletes the available plant-nutrient cations Ca^{2+}, Mg^{2+}, and K^{+}, it increases the leaching of aluminum, and it increases the amount of sulfur and nitrogen in the soil. All lead to weakening of trees, leading to their death by bark beetle infestations and disease.

Effect on abiotic items

Another class of victims of acid rain is entirely within the realm of human culture and history. Acid's ability to corrode metal, paints, limestone, and marble has accelerated erosion of buildings, bridges, statues, monuments, tombstones, and automobiles (**Figure** below).

Acid rain accelerates erosion of statues, monuments, buildings, tombstones, bridges, and motor vehicles.

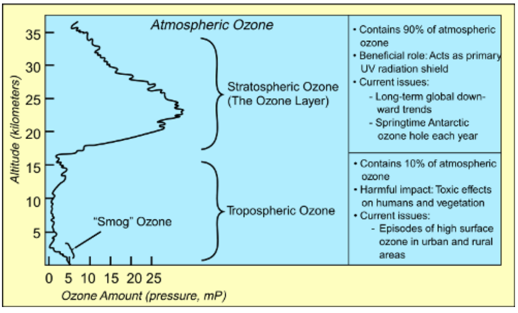
Attempts to solve the problem of acid rain began with building taller smokestacks. These only sent the polluting gases higher into the atmosphere, relieving local problems temporarily, but sending the damage to areas far from their industrial sources. Today in the U.S. and other western nations, smokestacks increasingly use "scrubbers" which remove as much as 95% of SO_X from exhausts; the resulting sulfates "scrubbed" from the smokestacks can sometimes be sold as gypsum (used in drywall, plaster, fertilizer and more), but may also be landfilled. Catalytic converters and other emission control technologies remove NO_X from motor vehicle exhaust. However, population growth and development throughout the world is increasing pressures to use more fossil fuels and high-sulfur coal, often without these expensive technologies.

Ozone Depletion

Ozone is found in two regions of the atmosphere:

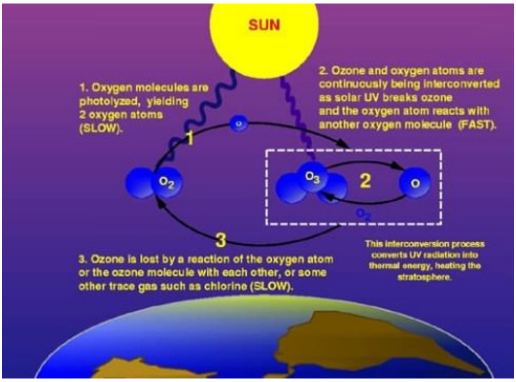
1. In the stratosphere at heights around 20–30 km, where it is produced by sunlight. This is good ozone. It is critical for life because it protects all life on earth from dangerous solar ultraviolet radiation, especially UVB, a band of ultraviolet radiation with wavelengths from 280–320 nanometers produced by the sun. Ultraviolet radiation with wavelengths from 320–400 nanometers, UVA, is not absorbed, and it is much less dangerous to life.
2. Close to the surface, where it is produced by sunlight acting on atmospheric pollutants. It is produced from nitrogen oxides and volatile carbon-based compounds when there is intense sunshine, above all in the spring and summer. This is bad ozone. It causes respiratory illness; it damages plants; and it attacks rubber.

Many people confuse the "hole in the ozone" with "global warming." Although the two are related in part, they are separate problems with separate effects and only partially overlapping causes, so they require separate solutions.



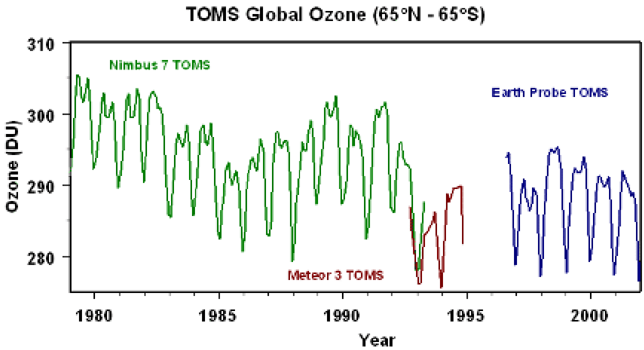
At altitudes less than 5 kilometers, respiratory irritant

Ozone is both a threat and a gift (**Figure** below). As a ground-level product of the interaction between sunlight and pollutants, it is considered a pollutant which is toxic to animals' respiratory systems. However, as a component of the upper atmosphere, it has shielded us and all life from as much as 97-99% of the sun's lethal UV radiation for as long as 2 billion years. The "hole" in the ozone develops in this thin upper **Ozone Layer**. How long will that protection continue? Let's explore the problem of ozone depletion.



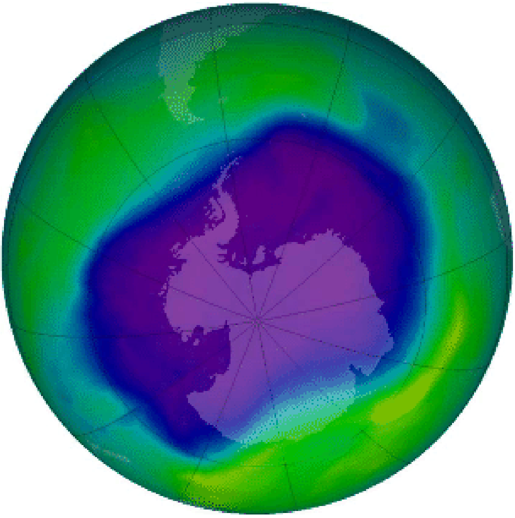
The ozone cycle involves the conversion of oxygen molecules to ozone (1 and 2) a slower reconversion of ozone molecules to oxygen (3). Interactions among ozone molecules or the presence of other reactive gases trigger the loss of ozone.

The Ozone (O_3) Layer forms when UV radiation strikes oxygen molecules (O_2) in the stratosphere, between 15 and 35 kilometers above the Earth's surface. Even the highest concentrations of ozone are only about 8 parts per million, but ever since photosynthesis oxygenated the Earth's atmosphere, allowing ozone-forming chemical reactions, this thin Ozone Layer has shielded life from the mutagenic effects of ultraviolet radiation – especially the more damaging UV-B and UV-C wavelengths (**Figure** above).

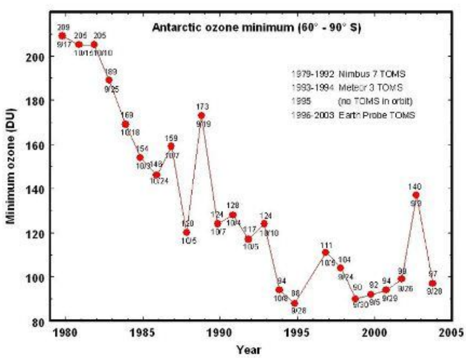


Total global monthly ozone levels measured by three successive spectrometers (TOMS) show both seasonal variations and a general decline.

The thickness of the Ozone Layer varies seasonally and across the Earth – thicker in Spring than in Autumn, and at the Poles compared to near the Equator. **Ozone depletion** describes two related declines in stratispheric ozone. One is loss in the total amount of ozone in the Earth's stratosphere – about 4% per year from 1980 to 2001 (**Figure** below). The second, much larger loss refers to the **ozone hole** – a seasonal decline over Antarctica (**Figures** below and 14), which has now lost as much as 70% of pre-1975 ozone levels. A much smaller "dimple" overt the North Pole has also shown a 30% decline. The Antarctic ozone hole occasionally affects nearby Australia and New Zealand after annual breakup. A secondary effect is the decline in stratosphere temperatures, because when ozone absorbs UV radiation, it is transformed into heat energy.



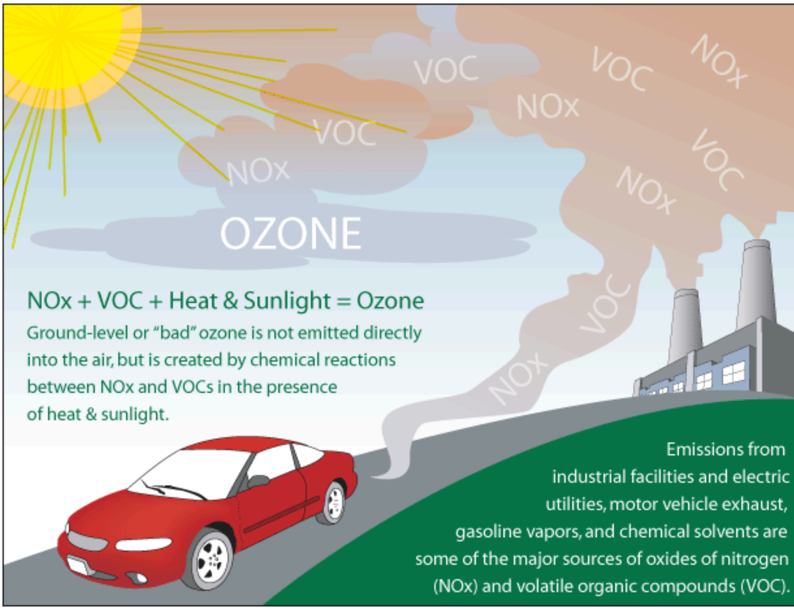
On September 24, 2006 the seasonal ozone hole over the Antarctic covered a record daily area (29.5 million square kilometres or 11.4 million square miles). Blue and purple areas show the lowest ozone levels, and green, yellow, and red indicate successively higher levels.



Lowest annual values of ozone in the ozone hole decreased dramatically between 1980 and 1995. Before 1980, values less than 200 Dobson units were rare, but in recent years, values near 100 units are common. Unusually high temperatures in the Antarctic stratosphere may have caused the high reading in 2002.

Ozone is Good Up High Bad Nearby. It is good when it occurs in the stratosphere, where it absorbs ultraviolet radiation (energy) from the sun. It is bad when it occurs close to the ground in the troposphere, where it is a pollutant. Tropospheric ozone irritates the respiratory system, aggravates asthma and bronchitis, and it inflames the lining of the lungs. It harms vegetation and agricultural crops, and it damages rubber and other materials.

Ozone is the major component of smog. It is produced from nitrogen oxides and volatile carbon-based compounds when there is intense solar radiation (energy), above all in the spring and summer. See The Physics and Chemistry of of Ozone. For more information: see the Environmental Protection Agency's page



Chemical reactions leading to ozone formation in cities. Click on image for a zoom. From Environmental Protection Agency.

http://oceanworld.tamu.edu/resources/environment-book/Images/ozoneform.gif?action=jump.jump_ozone

The causes of ozone depletion are gases which unbalance the ozone cycle (**Figure** above) toward the breakdown of ozone. Chlorine and bromine gases have increased due to the use of *chlorfluorocarbons* (CFCs) for aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers. These ozone-depleting substances (ODS) escape into the stratosphere, and when UV radiation frees chlorine and bromine atoms, these unstable atoms break down ozone. Scientists estimate that CFCs take 15 years to reach the stratosphere, and can remain active for 100 years. Each chlorine atom can catalyze thousands of ozone breakdown reactions.

Ozone depletion and the resulting increase in levels of UV radiation reaching earth could have some or all of the following consequences:

- effects on human health
- increase in skin cancers, including melanomas
- increased incidence of cataracts
- decreased levels of vitamin A
- possible increase in levels of vitamin D produced by the skin
- reduced abundance of UV-sensitive nitrogen-fixing bacteria
- loss of crops dependent on these bacteria
- disruption of nitrogen cycles
- loss of plankton (supported by a supernova-related extinction event 2 million years ago)
- disruption of ocean food chains

Most of these effects are based on the ability of UV radiation to alter DNA sequences. It is this potential which has made the Ozone Layer such a gift to life ever since photosynthesis provided the oxygen to fuel its production. Its total loss would undoubtedly be devastating to nearly all life.

In 1987, 43 nations agreed in the Montreal Protocol to freeze and gradually reduce production and use of CFCs. In 1990, the protocol was strengthened to seek elimination of CFCs for all but a few essential uses. Today, Hydrochlorofluorocarbons (HCFCs – similar compounds which replace one chlorine with a hydrogen) have replaced CFCs, with only 10% of their ozone-depleting activity levels. Unfortunately, HCFCs are greenhouse gases (see next lesson), so their role as alternatives is a mixed blessing. HFCs (hydrofluorocarbons) are another substitute; because these contain no chlorine, they have no ozone-depleting activity, and their **greenhouse effect** is less than HCFCs (though still significant). One HFC is currently used in automobile air conditioners in the U.S.

If ozone-depleting substances have been virtually eliminated, is ozone depletion no longer a problem?

Unfortunately, we have not yet reached that point. Levels of CFCs in the atmosphere are beginning to decline, and ozone levels appear to be stabilizing (**Figures** above and 14) for years after 2000). Scientists predict that ozone levels could recover by the second half of this century; the delay is due to the long half-life of CFCs in the stratosphere. However, recovery could be limited or delayed by two unknowns:

1. Developing countries outside the Montreal Protocol could increase their use of CFCs.
2. According to scientists, global warming would cool the stratosphere and increase ozone depletion because cooler temperatures favor ozone decomposition.

Preventing Air Pollution

Throughout this lesson, we have discussed solutions to specific problems for our atmosphere. A quick recap of ways to maintain our atmosphere and its ecosystem services from this chapter includes:

- Reducing use of fossil fuels
- Switching to cleaner fuels, such as nuclear power
- Switching to renewable energy sources
- Increasing fuel efficiencies
- Supporting legislation for fuel efficiencies
- Supporting national and international agreements to limit emissions
- Utilizing pollution control technologies: e.g., scrubbers on smokestacks and catalytic converters for motor vehicles
- Creating and supporting urban planning strategies

As always, costs are high and tradeoffs must be considered. The classic example is nuclear power, whose effects on the atmosphere are less than those of fossil fuels. Unfortunately, it has high potential for health damage and high costs – both economic and environmental – for storage and transport of nuclear waste.

5. Global Atmospheric Changes

JEAN BRAINARD

What is Climate

Traditionally, climate has been defined as the average weather: temperature, precipitation, cloudiness, and how these variables change throughout the year. Now, earth-system science leads to a much broader definition.

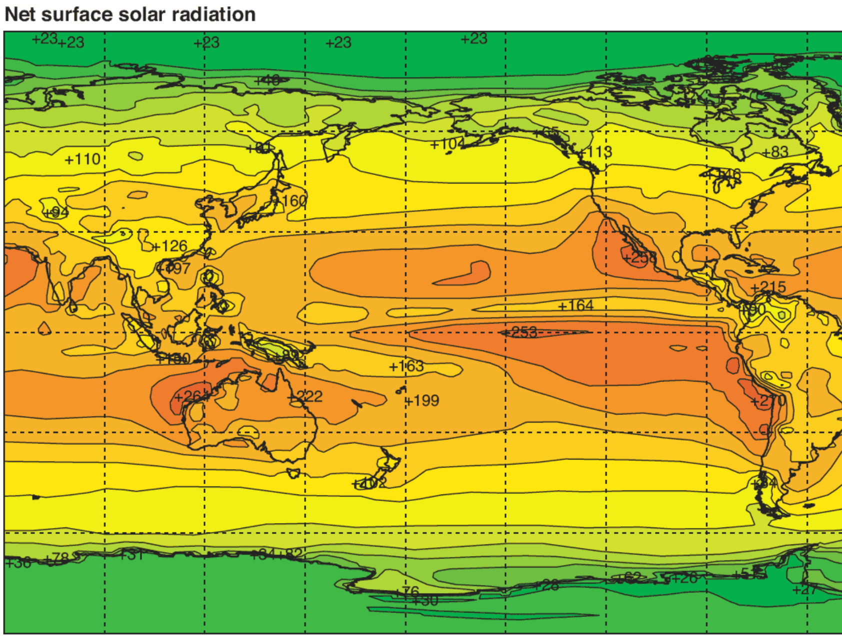
> For many, the term "climate" refers to long-term weather statistics. However, more broadly and more accurately, the definition of climate is a system consisting of the atmosphere, hydrosphere, lithosphere, and biosphere. Physical, chemical, and biological processes are involved in interactions among the components of the climate system. Vegetation, soil moisture, and glaciers, for example, are as much a part of the climate system as are temperature and precipitation. Pielke (2008).

The Ocean Strongly Influence Earth's Present Climate

The ocean drives the atmospheric circulation by heating the atmosphere, mostly in the tropics.

1. Most of the sunlight absorbed by earth is absorbed at the

top of the tropical ocean. The atmosphere does not absorb much sunlight. It is too transparent. Think of a cold, sunny, winter day at your school. All day long, the sun shines on the outside, but the air stays cold. But if you wear a black coat outside and stand out of the wind, the sun will quickly warm up your coat. Sunlight passes through the air and warms the surface of the ocean, just as it warms the surface of your coat. Most of the ocean is a deep navy blue, almost black. It absorbs 98% of the solar radiation when the sun is high in the sky.

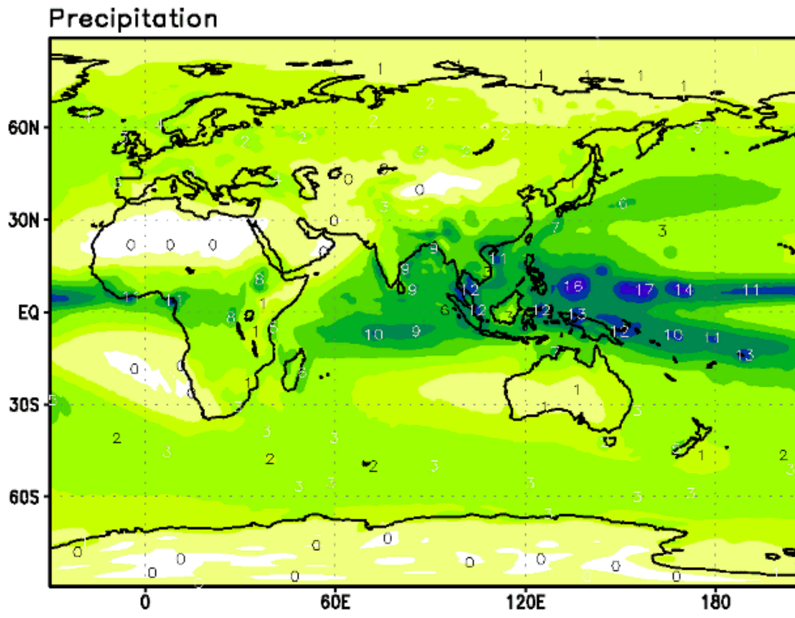


Heating of earth's surface by solar radiation, in W/m^2, calculated from the ECM
data. Notice that most of the heat absorbed by earth goes into the tropical oce

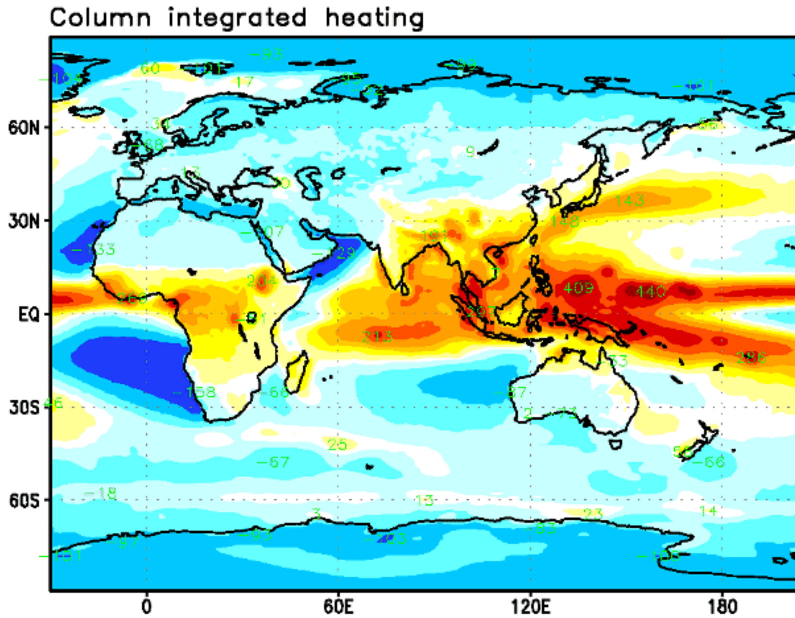
2. The ocean loses heat by evaporation (the technical term is latent heat release). Think of this as the ocean sweating. Trade winds carry the evaporated water vapor to the Inter-Tropical Convergence Zone where it condenses as rain.

Condensation releases the latent heat and warms the air. Warm air rises, further drawing in warm wet air, releasing more heat. Large areas of the tropical ocean get more than 3 m (115 inches) of rain each year (8 mm/day in the figure below).

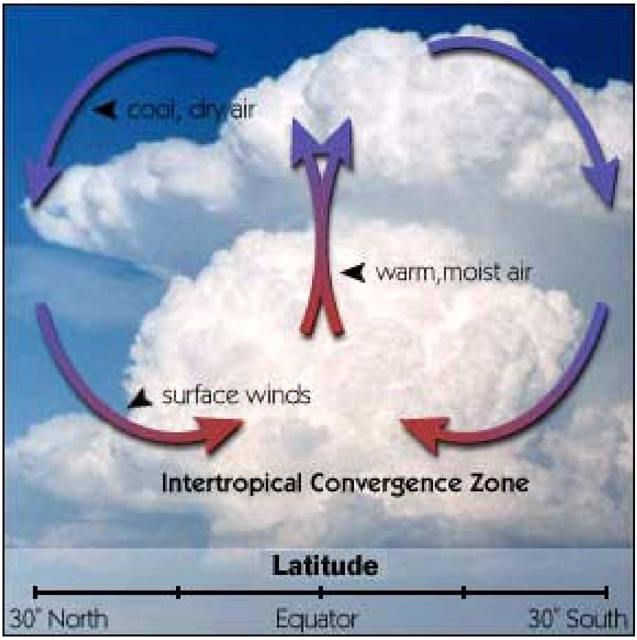
1. So much heat is released by rain in the Inter-Tropical Convergence Zone that it drives much of the atmospheric circulation. This circulation is called the Hadley circulation.
2. Heat released by rain in higher latitudes drives storms and winds.
3. Heat released by rain in hurricanes and thunderstorms drives these storms.

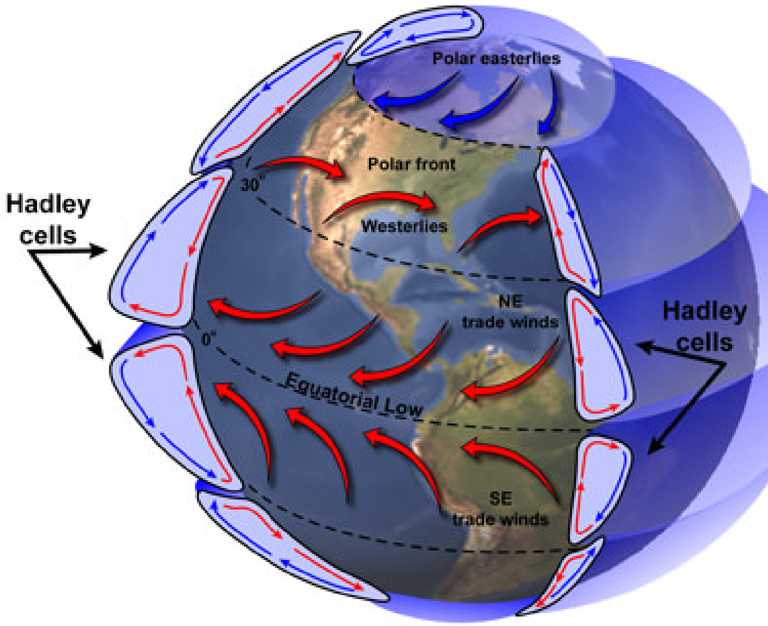


25-year average of rain rate. From Japan Meteorological Agency, Japanese



25-year average of heating of the atmosphere. Notice the high correlation
absorption of infrared radiation heats the atmosphere, mostly in the tropic
circulation. From Japan Meteorological Agency, Japanese 25-year Reanalys


cool, dry air
warm,moist air
surface winds
Intertropical Convergence Zone
Latitude
30° North
Equator
30° South



Upper: Rain in the tropics warms the atmosphere and drives the Hadley
Bottom: The Hadley cells (circulation) are a major part of the climate syst
from NASA Earth Observatory, Fewer Clouds Found In Tropics.

http://whyfiles.org/174earth_observe/4.html

3. The ocean also loses heat by sending out infrared radiation (energy), mostly in the tropics. The infrared radiation is absorbed by water vapor in the tropical atmosphere, further heating the atmosphere.
4. The winds drive ocean currents, and together they carry heat from the tropics to the polar regions. See The Climate System below.

The Ocean Influences Regional Climate

1. The difference in temperature between the land and the ocean drives monsoons. During the winter, the center of a continent is much colder than the surrounding ocean. This causes cold air to flow out of the continent. During the summer, the center of continent is much hotter than the ocean. This draws moist air into the continent bring much needed summer rains. Monsoon winds are especially important for Asia and North America. Arizona, and the American southwest get summer rains. from the North American monsoon. India gets rain during the Asian monsoon.

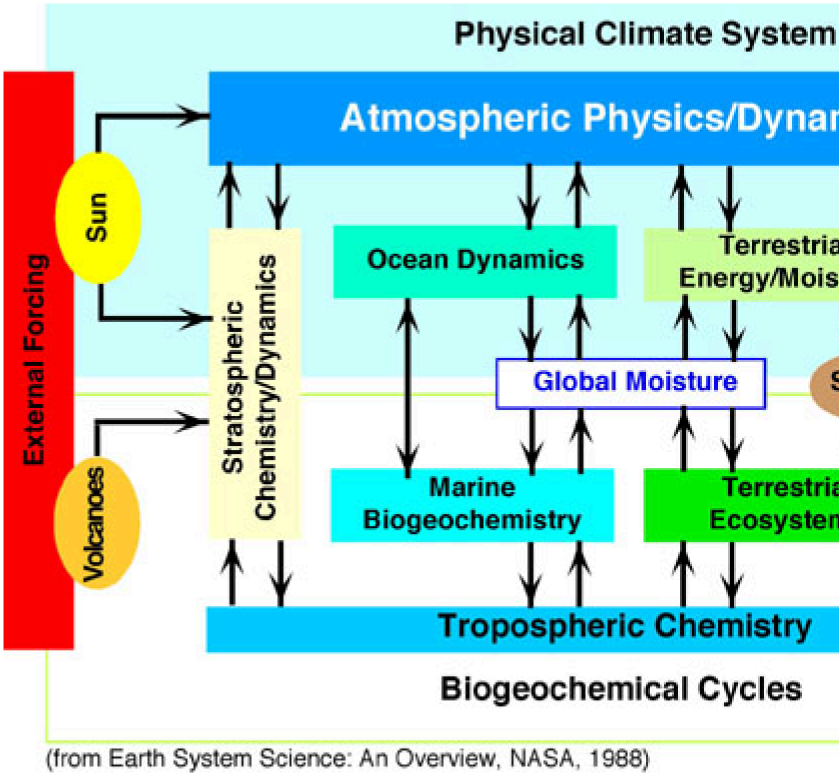
Arizona thunderstorm. Such storms in the American west are common in sum the North American monsoon. Click on the image for a zoom. From the Nation Service Forecast Office Flagstaff Arizona's article on the monsoon.

2. Cities along coasts benefit from the sea breeze. It too is due to the difference in temperature between the land and the ocean. During the night the land is cooler, and during the day it is warmer. The contrast in temperature causes winds to blow toward the ocean at night, and toward the land during the day.

Everything Is Connected

From this simple discussion of the climate system, we can conclude that we must understand how earth, with its atmosphere, greenhouse gases, ocean, life, winds, and currents all interact to produce our climate. The ocean is one big part of the earth system. The ocean, atmosphere, and land are connected through the climate system. Changes in one area cause changes everywhere else. Everything is connected, and everything influences everything else.

For example, rain heats the atmosphere. The warm air rises, creating wind. Wind drives ocean currents. Currents help determine where phytoplankton live. Phytoplankton help determine where clouds are formed. Clouds influences where the atmosphere is heated. Heating determines where the ocean evaporates, and the amount of evaporation.



There are many interacting parts in the earth system.

As a result of these connections:

1. Earth has a surface temperature that is just right for life. Water vapor from the ocean is essential for setting the earth's temperature.
2. The tropical ocean supplies almost all the water that falls on land.
3. The ocean absorbs half of the carbon dioxide released by our burning of fossil fuels. This reduces global warming caused by carbon dioxide.
4. So much heat is absorbed by the oceans, that the the

warming of earth's surface by greenhouse gases is slowed down. 84% of the energy available to warm earth's surface has gone into the ocean during the 48 years from 1955 to 2003; 5% has gone into the land; 4% has gone into the atmosphere; and the remainder has gone into melting ice. (Levitus, 2005).

The Carbon Dioxide Problem

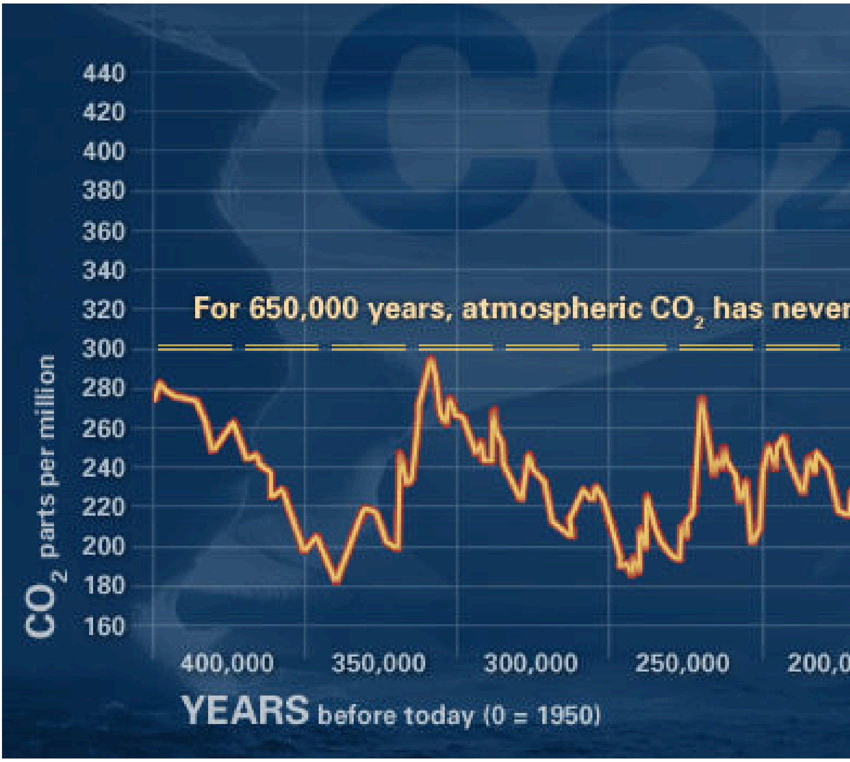
The carbon dioxide problem can be stated relatively simply:

1. More than six and a half billion people burn fuel to keep warm, to provide electricity to light their homes and to run industry, and to move about using cars, buses, boats, trains, and airplanes.
2. The burning of fuel produces carbon dioxide, which is released to the atmosphere.
3. The burning of fuels adds about 6 gigatons of carbon to the atmosphere each year.
4. Carbon dioxide concentrations in the atmosphere have risen from about 270 parts per million (0.026%) before the industrial age to about 380 parts per million (0.038%) by 2006, a 41% increase over pre-industrial values, and a 31% increase since 1870.
5. Carbon dioxide is a greenhouse gas, and the increased concentration of carbon dioxide in the atmosphere must influence earth's radiation balance.

Measurements of Temperature and Carbon Dioxide

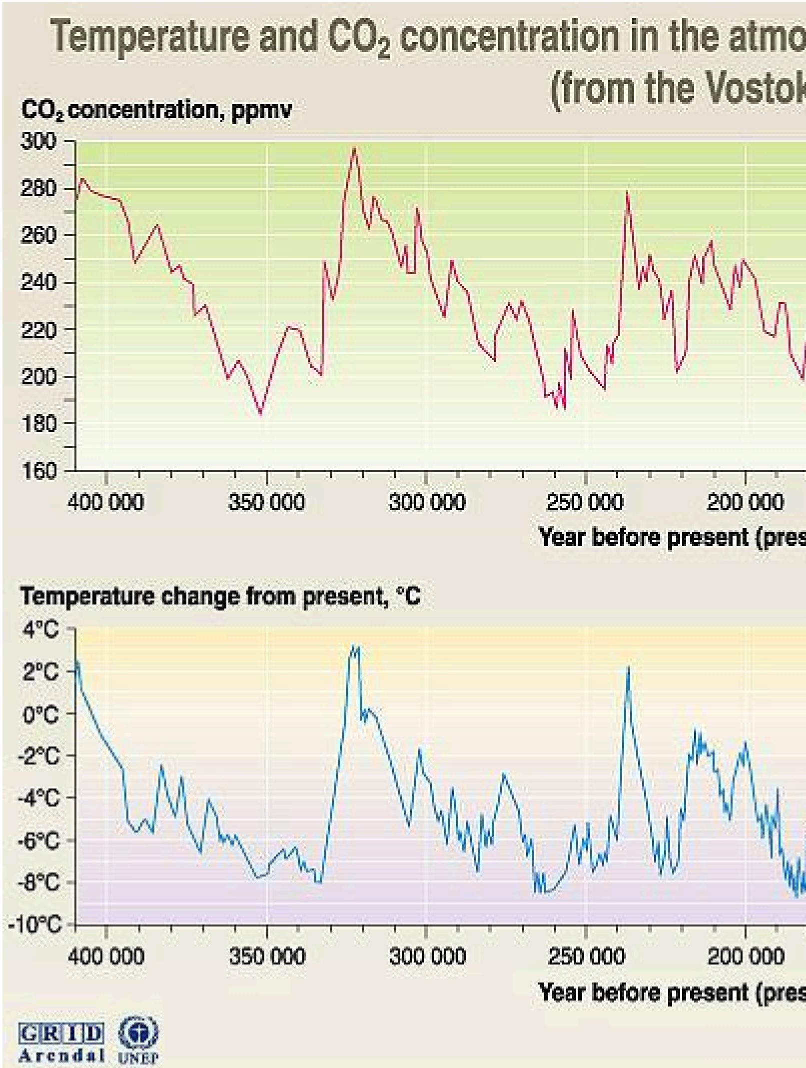
Measurements of carbon dioxide can be made at any location on earth remote from nearby local sources because the atmosphere is well mixed over periods of a few years. The two most famous sets of measurements were made at Mauna Loa in Hawai'i and at Vostok station in Antarctica.

1. Charles Keeling began collecting flasks of air from an observatory at the summit of Mauna Loa in Hawai'i in 1959. Keeling, the first to confirm the rise of atmospheric carbon dioxide by very precise measurements that produced a data set now known widely as the "Keeling Curve." Prior to his investigations, it was unknown whether the carbon dioxide released from the burning of fossil fuels and other industrial activities would accumulate in the atmosphere instead of being fully absorbed by the oceans and vegetated areas on land. From Charles David Keeling: Climate Science Pioneer.



This graph, based on the comparison of atmospheric samples contained in ice
evidence that atmospheric CO_2 has increased since the Industrial Revolution. (

2. The Vostok ice core is a cylinder of ice collected by drilling from the surface to near the bottom of the Antarctic ice sheet. Total length was 2083 meters, brought back in 4-6 meter sections. The core shows annual layers, which can be used to date the air bubbles trapped in the ice. Analysis of the gas content of the bubbles gives the concentration of carbon dioxide in the atmosphere when the ice formed. Ratios of oxygen isotopes and deuterium gives air temperature at the station at the time ice was formed.



1. Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in
 Atmospheric carbon dioxide concentration calculated from air bubbles tra
Vostok ice Station. Notice that present carbon dioxide concentrations far ex
concentration is high when temperature is high. This does not imply cause
through feedback loops. Both variables change over periods of around 100,
axis. To learn more about the relation between carbon dioxide and tempera
UNESCO Introduction to Climate Change, GRID-Arendal.
2. The page on Evidence for Global Warming has more information on ice cor

Sources of Anthropogenic (Human-Produced) Carbon Dioxide

Anthropogenic (human-produced) carbon dioxide is mostly from the burning of fossil fuel: coal, oil, and natural gas. The burning of forests to produce agricultural land, and the burning of forest wood for heating and cooking add smaller amounts. The following information comes mostly from the Statistical Review of World Energy 2005 by British Petroleum.

1. Global energy use from fossil fuels was approximately 8,260 million metric tons oil equivalent, which is approximately 9,623 X 10^9 m^3 = a cube of oil 2.12 km on a side.
2. Global oil consumption in 2003 was 76,800,000 barrels of oil per day. Most of the remainder of our energy comes from natural gas and coal.
3. Per capita consumption of energy in the United States is about 57 barrels of oil equivalent per year. The energy is used to heat and light homes, offices, and stores, to power trucks and automobiles, and to operate machinery. 57 barrels of oil at $50/barrel = $2,850. If the energy were used entirely as electricity, it would cost about $7,300 per person per year.
4. Consumption of energy in the United States was approximately:
    1. 89.4% from burning fossil fuels.
        1. 39.1% oil
        2. 25.9% natural gas
        3. 24.4% coal
    2. 8.1% from nuclear energy
    3. 2.5%from hydroelectric power plants
5. The United States used approximately 24% of all the

world's energy, although we are only 4.6% of the world's population.

Anthropogenic sources are a small part of the global carbon system. Their production mixes with carbon dioxide released by the respiration of plants and animals, and through the decay of carbon-based material from plants and animals.

Other Greenhouse Gases

Carbon dioxide is one of several greenhouse gases released in large quantities by human activities. The important gases are:

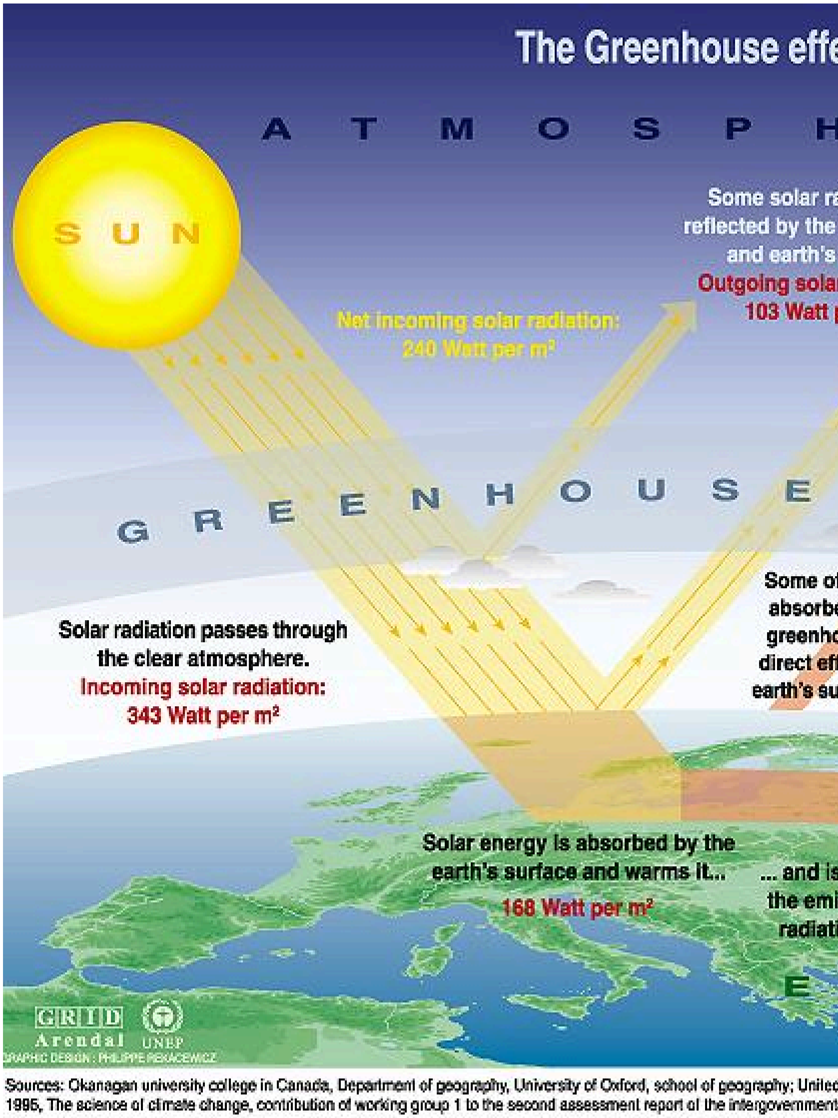
1. Water vapor. This is by far the most important greenhouse gas. It evaporates mostly from the ocean, and it causes earth's surface to be about 30°C warmer (out of the 33°C of warming caused by all greenhouse gases combined). See Ocean and Climate for a discussion of how much water warms the atmosphere.
2. Carbon dioxide.
3. Methane. It is produced by bacteria in wetlands and bogs, cattle, rice paddies, termites, landfills, and coal mining. About two thirds of the emissions into the atmosphere come from human activity, mostly in the northern hemisphere. Methane concentration was 1783 parts per billion in 2004, which was 155% larger than pre-industrial concentrations. The rise in methane appears to have leveled off, and concentrations have increased only 5 parts per billion since 1999. Methane does not remain long in the atmosphere, about 8 years (Fischer et al, 2008), so emissions and sinks are already close to balance. One pound of methane is 22 time more effective in absorbing infrered radiation than is a pound of carbon dioxide. The Department of Meteorology at the University of Maryland

College Park has a web page listing the amounts emitted by various sources. x

4. Nitrous oxide, from microbes in the soil and the ocean, and from burning fossil fuels at high temperatures, such as car engines. About one-third of the emissions into the atmosphere come from human activity. N_2O concentrations were 319 parts per billion in 2004, which was 18% larger than pre-industrial concentrations. Its lifetime in the atmosphere is similar to that of carbon dioxide, about a century.
5. Halocarbons such as refrigerants used in air conditioners .
6. Tropospheric ozone, produced in smog.

How do greenhouse gases influence earth's surface temperature?

Earth's average surface is 32°C warmer than it would be if it had no atmosphere. A planet the size of earth at earth's distance from the sun, and in thermodynamic equilibrium with solar energy (sunlight), would have an average surface temperature of -18°C. Earth's mean, global surface temperature for the period 1901 to 2000 is 13.9°C, which is 32°C warmer. This increase in temperature is due to greenhouse gases in earth's atmosphere.



greenhouse effect. From the Introduction to Climate Change written by the U
Resources Information Database (GRID) office in Arendal Norway.

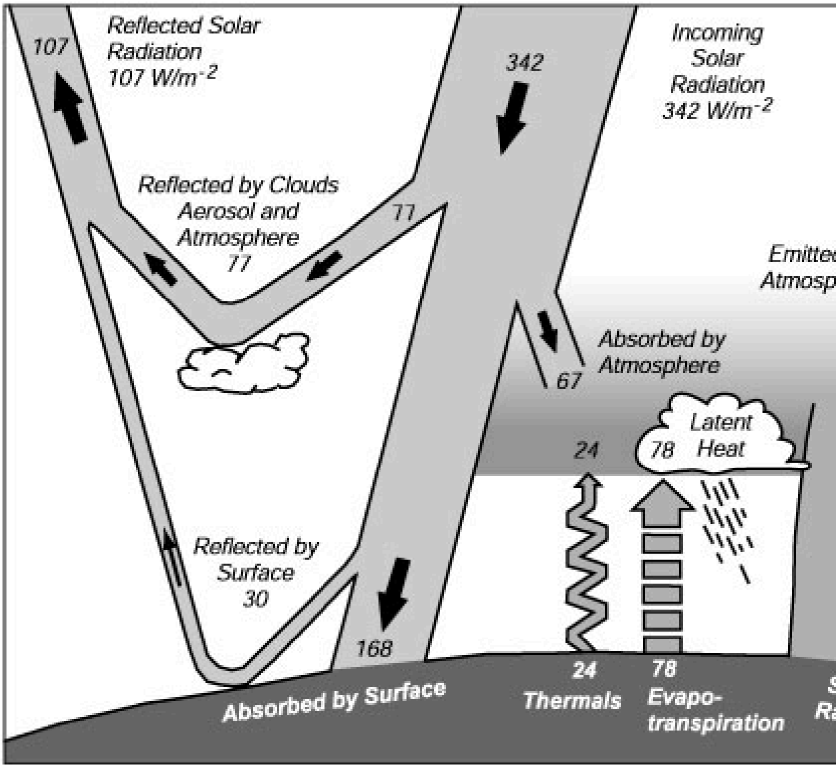
http://www.grida.no/climate/vital/03.htm

The basic idea is: the atmosphere is transparent to solar radiation. It allows sunlight to reach and warm the earth's surface. The atmosphere is mostly opaque to infrared radiation emitted from earth's surface, hindering the emission of radiation from the surface to space, keeping the surface warm.

Now, let's discuss the details of how greenhouse gases warm earth's surface. They are:

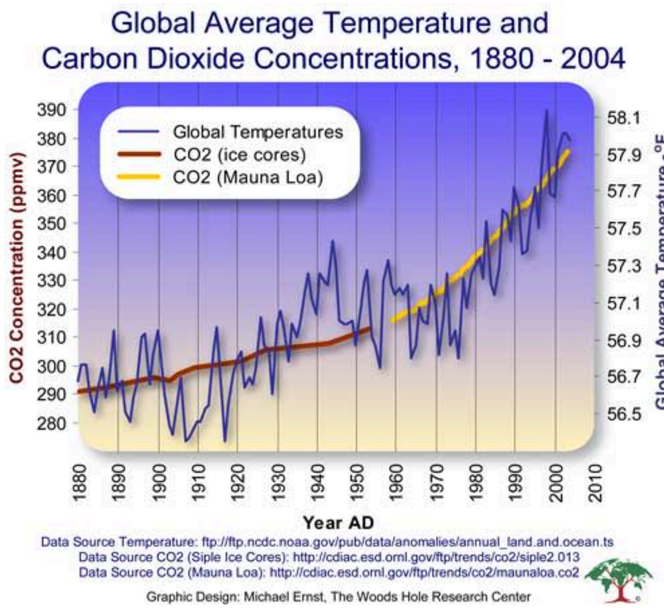
1. Sunlight reaches earth. It has an intensity of 1360 W/m^2, and the average over all the earth is 343 W/m^2. Remember, the average includes day and night, from the equator to the poles. Most solar energy has a wavelength close to 0.5 μm.
2. 49% of the incoming sunlight goes straight through the atmosphere and it is absorbed by earth's surface, mostly in the tropical ocean.
3. 31% of the incoming sunlight is reflected back to space, 22% by clouds, and 9% by the surface.
4. The remaining 20% is absorbed in the atmosphere.
5. Sunlight that is absorbed by earth's surface and atmosphere warms the surface and the atmosphere.

Thus greenhouse gases absorb radiant energy from earth's surface, and reradiate most of it back to the surface, keeping the surface warm. If there were no greenhouse gases, the surface would rapidly radiate heat away to space. The figure below shows these values a little more clearly.



The mean annual radiant energy and heat balance of the

What is the Evidence for Climate Change?



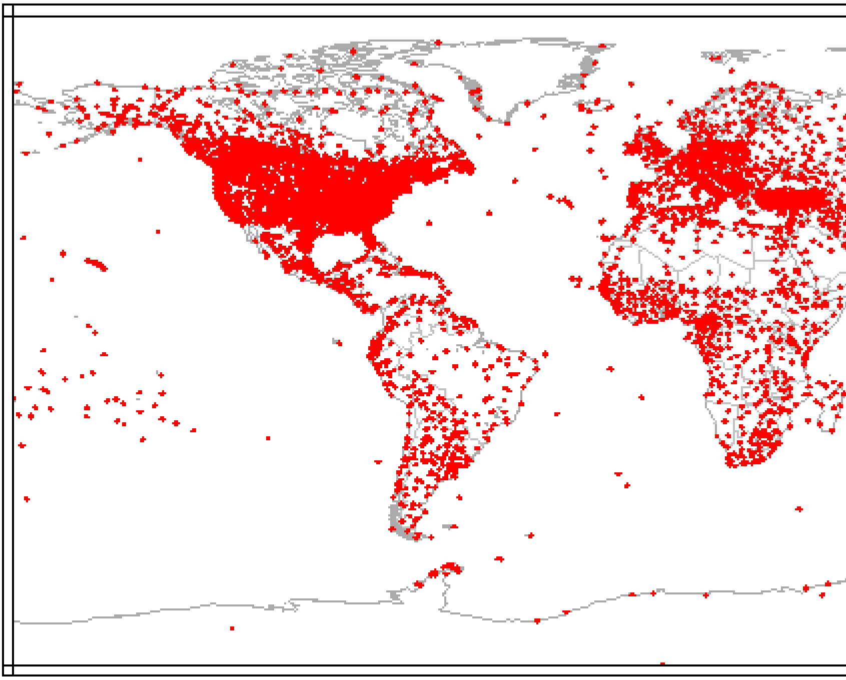
Carbon dioxide concentration in the atmosphere measured by David Keeling colleagues at Mauna Loa, Hawai'i and from polar ice cores, with average globa surface temperature of earth. Image from Woods Hole Research Center, presentation by Director John P. Holdren, The Scientific Evidence.

The plot above shows that earth surface is warming. Now let's look at the evidence used to make the plot.

1. Where do we get our information?
2. How do we know if the ocean or land temperatures are changing?
3. What is the evidence?
4. How good is the evidence?

Where do we get our information?

1. On land, temperature is measured a hundreds of weather stations, somewhat unevenly distributed around the world, and on some oceanic islands.



Map of land stations in the Global Historical Climatology Network where air te
From: NOAA National Climate Data Center.

http://www.ncdc.noaa.gov/img/climate/research/ghcn/ghcnv2.mean.gif

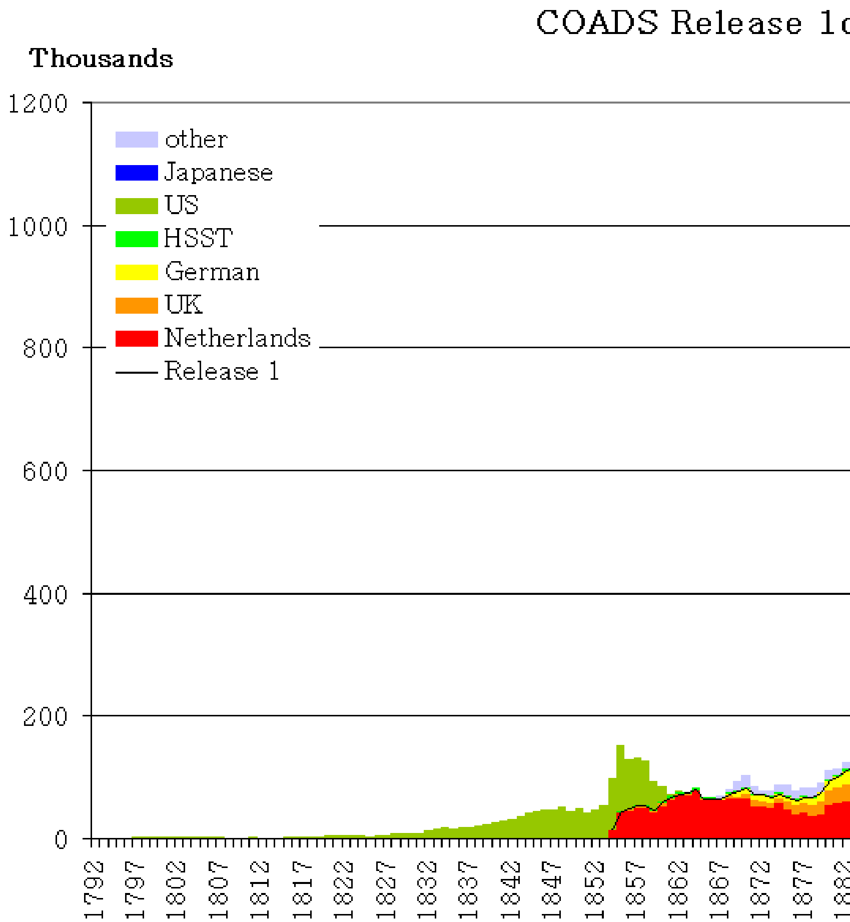
2. At sea, we get data from satellites and from ships. Satellite measurements of surface temperature come primarily from the Advanced Very High Resolution Radiometer (AVHRR) first launched in 1978 and operated continuously since then. The satellite data are calibrated

using ship observations of surface temperature from the same time and place. Accuracy of the combined ship and satellite data set, the Reynolds Optimum Interpolation Sea-Surface Temperature maps is about +- 0.3 degrees C on a one-degree (horizontal) grid.

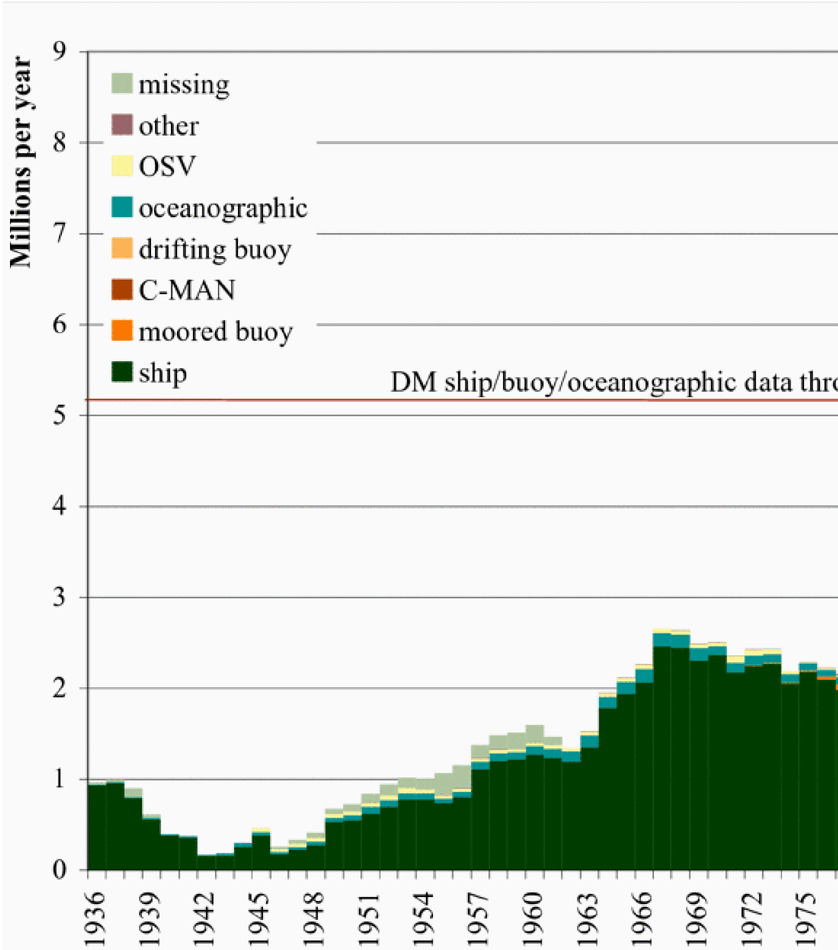
3. Data from the AVHRR are available with horizontal resolution of about 1 km. Such maps show much more detail than the Reynolds maps. For example, look at a map of sea-surface temperature in the Gulf of Mexico produced by the Johns Hopkins University Applied Physics Laboratory, Ocean Remote Sensing Group. Click on a few of the thumbnails to bring up the image.

    - How was the map made?
    - What problems might we have if we tried to determine average temperature of the ocean before satellites were available, by using data from ships?
    - To learn more, look at the sample images of the Gulf Stream.

4. Before 1978, all observations at sea were made from ships using thermometers to measure water samples collected in buckets (bucket temperature) or to measure water drawn into the ship to cool the engines (injection temperature). Approximately 185,000,000 observations have been collected, evaluated, and tabulated through the International Comprehensive Ocean Atmosphere Data Set (ICOADS) for the period 1784 to 2002. The data set is the monthly summaries of the observations. The monthly time series are available at 2-degree (1800-2002) and 1-degree (1960-2002) spatial resolutions. Very few observations are available before about 1850, and most are from 1900.



Number of reports of marine weather reports each year included in the Interna
(From NOAA Climate Diagnostics Center).



Number of reports of marine weather reports each year included in the Intern
in the period 1936 to 2005 in release 2.3 of the data set. Click on the image for

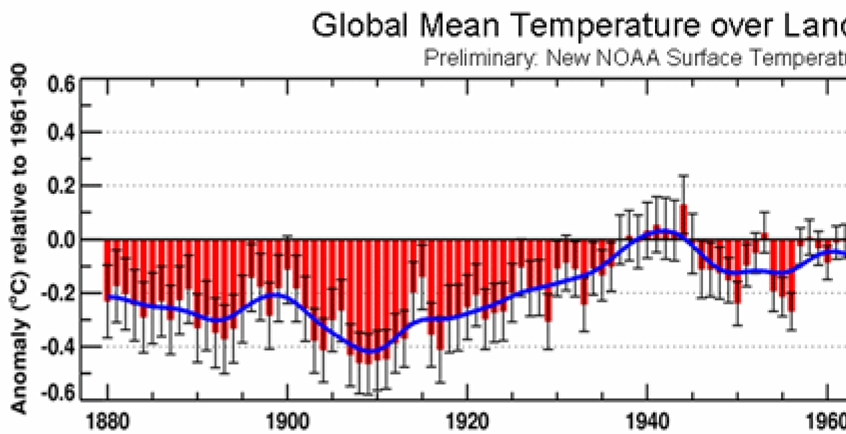
http://oceanworld.tamu.edu/resources/oceanography-book/Images/icoads-2.3-1939-2005.gif

Sources of error. Several sources contribute errors to the plot of earth's surface temperature temperature.

1. One important error is due to the large variability in the

the land and ocean temperature from region to region and month to month. Temperatures on land vary up to approximately 15-20 degrees C during the day at mid latitudes, and by up to approximately 50 degrees C from summer to winter. Over the oceans, the range is much smaller, approximately 7 degrees C from summer to winter.

2. The biggest error in the calculation is called the sampling error. We do not have enough measurements to determine if temperature is changing before about 1850, and we barely have enough even today. The error leads to some the year-to-year variability in the plot of global averaged surface temperature as as a function of time. Also read about the sampling error in oceanography (scroll down to find the box on *sampling error*.
3. Smith and Reynolds report that the 95% confidence uncertainty for the near-global average is 0.48C or more in the nineteenth century, near 0.28C for the first half of the twentieth century, and 0.18C or less after 1950.



Global average of sea-surface temperature calculated using Smith and Reynol values. From NOAA National Climate Data Center Climate 2005 Annual Report.

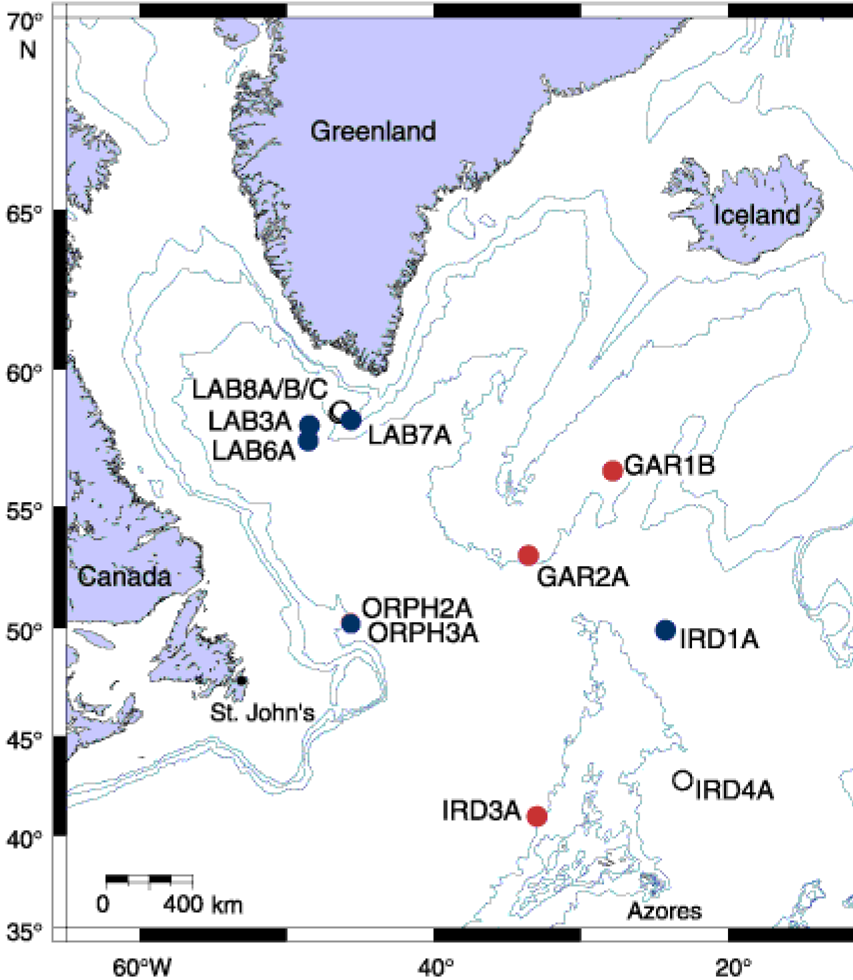
4. Instruments have some error. For example, water in

buckets made of canvas used from 1900 to 1940 cooled off quickly compared with water in wooden buckets used before 1900. This introduced systematic, small errors into global averages of sea-surface temperature. See Box 2.2: Adjustments and Corrections to Marine Observations in measurements of sea surface temperature and ocean air temperature in Climate Change 2001.
5. The urban heat island effect. Most measurements on land are made near cities. As cities grow, they heat the atmosphere over and near the city. This heating is due to the city, not to global warming. About 50% of the warming in the US may be due to heat islands and land use changes (Kalnay, 2003).

Evidence from the past 400,000 years.

The instrumental record based on direct measurements of temperature made by thermometers and satellite instruments goes back only a hundred and fifty years. To learn about more about earlier climate change we need to use proxy data, measurements of phenomena that depend on climate. Various types of proxy data are used:

1. Cores of the sea floor made by the Integrated Ocean Drilling Program IODP. For example, Expeditions 303 and 306 collected data on climate variability in the North Atlantic over tha past few million years. The data is used with data cores from the Greenland Ice Sheet.



Location of proposed drill sites. Blue circles = primary sites planned for Expedit
planned for Expedition 306, and open circles = alternate sites. From Expedition
Prospectus, Introduction.

2. Ice cores from thick ice sheets in Greenland, Antarctica, and mountain glaciers from around the world provide many different types of data:
    1. The layers give the age of the ice. For the latest ten thousand years of longer, counting the layers gives

age.

2. Learn more about evidence collected from ice cores by reading Deciphering Mysteries of Past Climate From Antarctic Ice Cores.
3. Stable isotopic composition, especially the ratio ($^{18}O/^{16}O$) where ^{18}O is the concentration of the oxygen 18 isotope, and ^{16}O is the concentration of oxygen 16 isotope, and the concentration of duterium. The oxygen isotope ratio and the duterium concentration give the temperature at which H_2O condensed as water or snow on the surface of the ice sheet.
4. Air bubbles trapped in the ice gives atmospheric gas content, especially the concentration of carbon dioxide.
5. Dust content in the ice depends on windiness over land upwind of the ice sheet.
6. Salt content in the ice depends on windiness over the ocean upwind of the ice sheet.
7. Sulphuric acid content of the ice depends on volcanic activity.

3. Dendrochronology uses measurements of the width of tree rings to determine relative changes in environmental conditions influencing the growth of trees. Change sin width provide information on droughts and temperature changes. See also dendrochronology at the Minnesota State University's E-Museum.
4. Analysis of pollen deposited in layered sediments in lakes gives the type of plants growing in the vicinity of the lake at different times. Types of plants depends on climate, and their types and abundance give information about past climates.

How Serious Is the Threat?

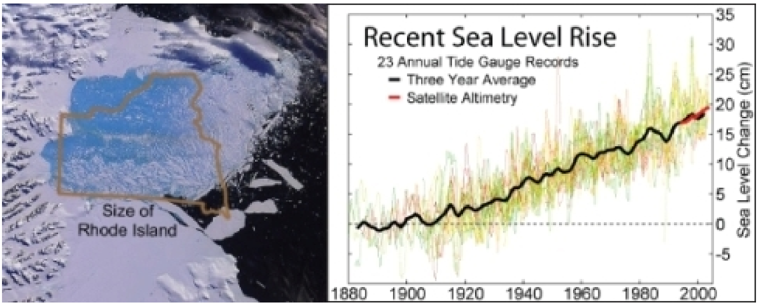
Scientific evidence for warming is convincing. Earth's surface is warming. The future is less certain. Do we even want to stop global warming?

> Given that the climate is changing because of inadvertent consequences of human activities, the question arises as to whether efforts should be made to deliberately change climate to counteract the warming. Aside from the wisdom and ability to do such a thing economically, the more basic question is the ethical one...Who makes the decision on behalf of all humanity and other residents of planet earth to change the climate deliberately? Climate change is not necessarily bad. Frosch and Trenberth (2009).

Our understanding of the importance of global warming depends on the accuracy of climate forecasts. Forecast accuracy depends on how well we understand earth's carbon cycle, economics, and politics. All influence warming. All are uncertain.

Direct Physical Effects

- Melting of glaciers and a consequent rise in sea level, already documented
- Sea level rise of 18-59 cm predicted by 2100
- River flooding followed by drought
- Coastal flooding and shoreline erosion



Glacial melting (left) and a rise in sea level (right) are two consequences of global warming. The left image shows the Larsen Ice Shelf B, which broke up during February of 2002 after bordering Antarctica for as long as 12,000 years. Excluding polar ice caps, 50% of glacial areas have disappeared since the turn of the century. Although sea levels have risen since the end of the last Ice Age, rates increased by a factor of 10 beginning about 1900.

- Melting permafrost, leading to release of bog methane (CH_4) increasing warming via positive feedback*
- Changing patterns of precipitation
- Regional drought
- Regional flooding
- Ocean warming, leading to increased evaporation
- Increasing rainfall
- Increasing erosion, deforestation, and desertification
- Release of sedimentary deposits of methane (CH_4) hydrates – positive feedback*
- Ocean acidification: 0.1 pH unit drop already documented; 0.5 more predicted by 2100
- Loss of corals
- Loss of plankton and fish
- Temperature extremes
- Increasing severity of storms such as tropical cyclones, already documented
- Further reductions in the Ozone Layer (due to cooling of

the stratosphere)

The proportion of hurricanes reaching category 4 or 5 increased from 20% in the 1970s to 35% in the 1990s. The EPA and the World Meteorological Organization connect this increase to global warming, and NOAA scientists predict a continuing increase in frequency of category 5 storms as greenhouse gases rise.

Ecosystem Effects

- Contributions to the Sixth Extinction reaching as much as 35% of existing plant and animal species
- Decline in cold-adapted species such as polar bears and trout
- Increase in forest pests and fires
- Change in seasonal species, already documented
- Potential increase in photosynthesis, and consequent changes in plant species
- Loss of carbon to the atmosphere due to
- Increasing fires, which together with deforestation lead to positive feedback
- Increasing decomposition of organic matter in soils and litter

Socioeconomic Threats Result From Some of the Above Changes

In determining policy, the cost of future damages C due to climate change must be converted to their present value C_t, where:

1. Present value is the value on a given date of a future payment or series of future payments, discounted to reflect the time value of money and other factors such as investment risk. Present value calculations are widely used in business and economics to provide a means to compare cash flows at different times on a meaningful "like to like" basis. From Wikipedia article on Present Value.

The present value C_t of a future expense C is calculated from $C_t = C (1 + i)^{-t}$, where t is the time in years, and i is the cost of money, usually an assumed interest rate that could be earned if the money were invested. The assumed interest rate is controversial because a small change in the rate makes a large difference in the present value if time is several decades or a century. For example, a cost of $1000 that will be incurred in 50 years has a present value of $87.20 if i = 5%, and a value of $54.29 if i = 6%. For more on this problem, read the Hoover Digest article An Economist Looks at Global Warming by Gary S. Becker, who was awarded the Nobel Prize for Economics in 1992.

Possible socioeconomic issues include:

- Crop losses due to climate and pest changes and desertification

- Increasing ranges for disease vectors (e.g., mosquitoes – malaria and dengue fever)
- Losses of buildings and development in coastal areas due to flooding
- Interactions between drought, desertification, and overpopulation leading to increasing conflicts (**Figure** below)

A camp in Sudan houses refugees from the far western province of Darfur, who fled from genocide intensified by severe drought. The Darfur conflict echoes predictions that global warming may increase drought and desertification in overpopulated regions and result in more such tragedies.

- Costs to the insurance industry as weather-related disasters increase
- Increased costs of maintaining transportation infrastructure
- Interference with economic development in poorer nations
- Water scarcity, including pollution of groundwater
- Heat-related health problems

Threats to Political Stability

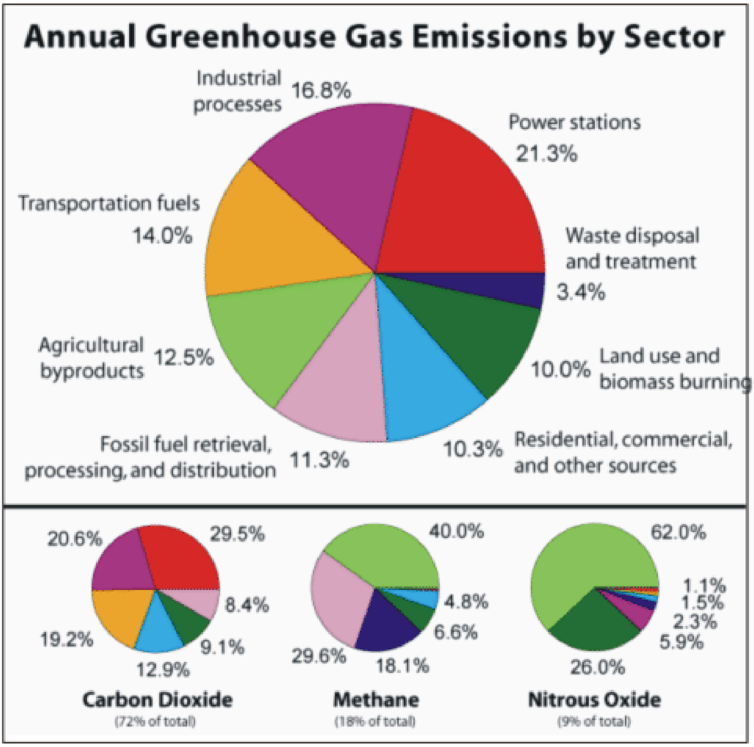
- Migrations due to poverty, starvation, and coastal flooding
- Competition for resources

Note that at least three(*) of the direct physical effects – melting permafrost, ocean warming, and forest fires/ deforestation – can potentially accelerate global warming, because temperature increases result in release of more greenhouse gases, which increase temperatures, which result in more greenhouse gases – a positive feedback system aptly termed a "**runaway greenhouse effect**." Here's how it could work: rising temperatures are warming the oceans and thawing permafrost. Both oceans and permafrost currently trap huge quantities of methane – beneath sediments and surface – which would undergo massive releases if temperatures reach a critical point. Recall that methane is one of the most powerful greenhouse gases, so the next step would be further increase in temperatures. Warmer oceans and more thawed permafrost would release more quantities of methane – and so on. These compounding effects are perhaps the most convincing arguments to take action to reduce greenhouse gas emission and global warming.

What measures have been considered?

Preventing Climate Change

Basically, greenhouse gases are products of fossil fuel combustion; according to the EPA, more than 90% of U.S. greenhouse gas emissions come from burning oil, coal, and natural gas. Therefore, energy use is the primary target for attempts to reduce future global warming. In **Figure** below you can see the sources of emission for three major greenhouse gases in 2000, when CO_2 was 72% of the total, CH_4 18%, and NO 9%. Chlorofluorocarbons (CFCs, HCFCs, and HFCs) are also greenhouse gases; refer to the lesson on The Atmosphere for more information about them.



Global greenhouse emissions during 2002 show sources for each of the three major greenhouse gases. Knowing the causes makes finding solutions clear, but not necessarily easy!

Knowing the causes of climate change allows us to develop potential solutions. Direct causes include combustion of fossil fuels, deforestation and other land use changes, cattle production, agriculture, and use of chlorofluorocarbons. Runaway effects can result from temperature-dependent release of methane from permafrost and ocean sediments, and forest fires or intentional burning. Unfortunately, the best way to avoid runaway effects is to prevent temperature increases. Prevention, then, should address as many of these causes as possible. A partial list of solutions being considered and adopted follows.

1. Reduce energy use.
2. Switch to cleaner “alternative” energy sources, such as hydrogen, solar, wind, geothermal, waste methane, and/or biomass.
3. Increase fuel efficiencies of vehicles, buildings, power plants, and more.
4. Increase **carbon (CO_2) sinks**, which absorb CO_2 – e.g., by planting forests.
5. **Cap emissions** release, through national and/or international legislation, alone or in combination with carbon offset options (see below).
6. Sell or trade **carbon offsets or carbon credits**. Credits or offsets exchange reductions in CO_2 or greenhouse emissions (tree-planting, investment in alternative energy sources, methane capture technologies) for rights to increase CO_2 (personally, as for air travel, or industry-wide).
7. Key urban planning to energy use, e.g., efficient public transportation.
8. Develop **planetary engineering**: radical changes in technology (such as building solar shades of dust, sulfates, or microballoons in the stratosphere), culture (population control), or the biosphere (e.g. iron-seeding of the oceans to produce more phytoplankton to absorb more CO_2).
9. Legislate Action: International agreements such as the 2005 Kyoto Protocol (which the US has not yet ratified), or national carbon taxes or caps on emissions. Interestingly, in the U.S., some States and groups of States are taking the lead here.
10. Set goals of carbon neutrality: in 2007, the Vatican announced plans to become the first **carbon-**

neutral state.

11. Support developing nations in their efforts to industrialize and increase standards of living without adding to greenhouse gas production.

Every potential solution has costs and benefits which must be carefully considered. Human health, cultural diversity, socioeconomics, and political impacts must be considered and kept in balance. For example, nuclear power involves fewer greenhouse gas emissions, but adds the new problems of longterm radioactive waste transport and storage, danger of radiation exposure to humans and the environment, centralization of power production, and limited supplies of "clean" uranium fuels. Studies of costs and benefits can result in solutions which make effective tradeoffs and therefore progress toward the goal of lowering greenhouse gases and minimizing future global warming.

We have reached the point where we understand how and the extent to which our activities have destabilized the Earth's atmosphere and reduced and threatened its ecosystem services. Now we need to move one step further, and put our knowledge to work in the form of action.

The Precautionary Principle

Faced with the uncertainty in our ability to predict future climate change, many argue in favor of the precautionary principle.

> 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. From The New Uncertainty Principle.

> Policymakers need to take a precautionary approach to environmental protection … We must acknowledge that uncertainty is inherent in managing natural resources, recognize it is usually easier to prevent environmental damage than to repair it later, and shift the burden of proof away from those advocating protection toward those proposing an action that may be harmful. From New Jersey governor Christine Todd Whitman In an October 2000 speech at the National Academy of Sciences in Washington, D.C.

The precautionary principle has been interpreted in many ways. In its strongest form

> The principle can be interpreted as calling for absolute proof of safety before allowing new technologies to be adopted. For example, the World Charter for Nature (1982) states "where potential adverse effects are not fully understood, the activities should not proceed." If interpreted literally, no new technology could meet this requirement. From "Science and the Precautionary Principle."

The strong form stifles progress. If the principle had been applied when fire was invented, we would still be eating our food raw. "If applied to aspirin, it would never have been licensed for sale." writes Helene Guldberg in Challenging the Precautionary Principle.

The principle is more useful in a weaker form. We need only require that present activity be modified if the future costs of present activity may greatly exceed the cost of changing present activity. For example, if the future cost of climate change may greatly exceed the cost of reducing emissions of greenhouse gases, then we ought to reduce the emissions.

When applied to climate change and global warming the important points are:

1. We have only one earth.
2. If greenhouse gas emissions cause large changes in climate, we may not be able to return to our present climate for centuries. CO_2 concentrations will remain high for more than 100 years, and temperature will continue to rise even if we stopped all emissions today, even if we do not know how much temperature will rise.
3. The economic and environmental costs of abrupt climate change far exceed the costs of slowly reducing greenhouse gas emissions (over the next two decades).
4. Therefore we ought to reduce emissions even if we are not sure they will cause abrupt climate change.
5. Two decades from now we will know much more about climate change, and at that time we can reassess our activity.

The principle may also apply in trying to reduce greenhouse gas. Reducing greenhouse gas to their pre-industrial level may not return earth to a pre-industrial climate.

> In a highly nonlinear feedback-controlled system like global climate, we would expect complex hysteresis effects: Decreasing a control variable such as greenhouse gas will not necessarily lead the climate back along some path like the one it followed when the control variable was increased. The end state of the control-variable manipulation may not at all resemble the original state before the control variable was increased, nor will it necessarily be a state we want to be in. Frosch and Trenberth (2009).

The Kyoto Protocol: A Framework for International Cooperation

Most of the governments of the world, are considering ways to reduce greenhouse gas emissions. The first global step toward reductions was the Kyoto Protocol. On February 16, 2005, the Kyoto Protocol entered into force without ratification by the United States. By July 10, 2006 164 nations and economic regional integration organizations had ratified the Protocol.

1. What is being proposed? The primary document is the Kyoto Protocol to the United Nations Framework Convention on Climate Change. According to the protocol "The Parties included in Annex I [the developed countries of the world] shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012." From Article 3 of the Kyoto Protocol.
2. How sound are the arguments that support or oppose the proposals?
    1. Read the US Congressional Research Service (CRS) abstract of their report on Global Climate Change: Major Scientific and Policy and the report (104 kByte pdf file) which gives a good overview of the policy issues up to 11 August 2006. The Kyoto Protocol became legally binding on 16 February 2005 at midnight New York time (0500 GMT). The countries that ratified the protocol agreed to cut their

greenhouse gas emissions between 2008 to 2012 to levels that are 5.2 per cent below 1990 levels.

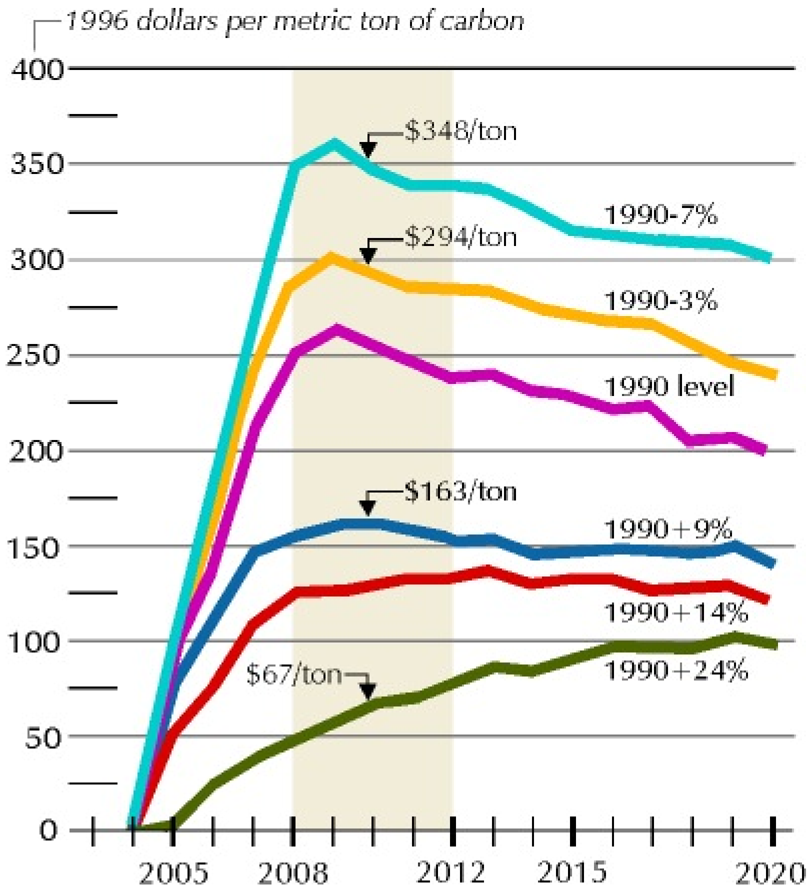
2. Then go the the Energy Information Administration's Analysis and Report and read about the implications for the US economy.
3. The United States has ratified the United Nations Framework Convention on Climate Change, but we have not ratified the Kyoto Protocol. The primary reasons for not ratifying the protocol include:

    1. It excludes the world's most populous countries, China and India, because they are developing countries. The US wanted meaningful participation by all countries.
    2. There is no clear statement of penalties for failure to implement the protocol.
    3. The protocol emphasizes sources of greenhouse gases, but atmospheric concentration depends on sources and sinks. The protocol did not give sufficient weight to implementing new sinks of greenhouse gases. For example, reforestation removes carbon dioxide from the atmosphere. Or, carbon dioxide could be removed from the atmosphere and injected into deep wells. To what extent can which carbon sequestration by forests, soils and agricultural practices be counted toward a country's emission reductions?
    4. It was not clear how much of a country's obligation to reduce emissions can be met through purchasing credits from outside, vs. taking domestic action.
    5. The role of emissions trading was not clear. The US would like to use emissions trading to meet a significant percentage of our required reduction in greenhouse gas emissions.
    6. It penalizes the US more than other countries

because our economy has been growing strongly compared with other countries that have ratified the protocol.

4. Although some of these problems were mitigated through later meetings of the Conference of the Parties (COP), the problems are still not completely solved.
5. Economists point out that the cost of reducing emissions now exceed the cost of reducing emissions in the future when we know more about the consequences of global warming.
6. Economists also point out that the cost of global warming is about equal to the benefits. Canada and Russia will gain, other economies will lose. "Given reasonable inputs, most cost-benefit models show that dramatic and early carbon reductions cost more than the good they do."– Stern Review: The dodgy numbers behind the latest warming scare. The Kyoto Protocol is a symbolically important expression of governments' concern about climate change. But as an instrument for achieving emissions reductions, it has failed. It has produced no demonstrable reductions in emissions or even in anticipated emissions growth. And it pays no more than token attention to the needs of societies to adapt to existing climate change. Time to Ditch Kyoto. Prins (2007)

3. What are the implications for TAMU students?



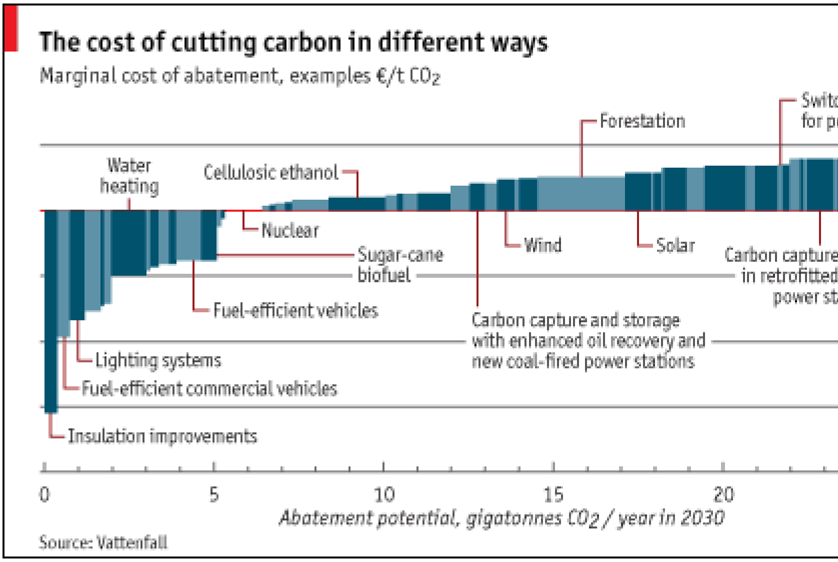
Carb
needed to meet Kyoto goals in the US. Price increases encourage a reduction in
of energy services (heating, lighting, and travel, for example), the adoption of m
energy-efficient equipment, and a shift to less carbon-intensive fuels. The carb
reflects the amount fossil fuel prices in the US, adjusted for the carbon content
fuel, must rise to achieve the removal of the last ton of carbon emissions that m
carbon reduction target in each case. From; Energy Information Agency. Note:
barrels of oil contain about 1 metric ton of carbon. US EPA Green Power Equiva
Calculator Methodologies.

Ways to Reduce Greenhouse gas Emissions

The Kyoto Protocol sets a goal for reducing greenhouse gas emissions. Each country must determine how to reach the goal. Three approaches are taken.

1. Command and control. The government decides what must be done. For example, the US Congress is proposing to set limits on gasoline mileage for cars. This approach is rarely effective. Drivers in the US switched from small cars to large, less-fuel efficient cars, despite government regulations on fuel efficiency, because the larger vehicles are safer and they are able to carry children and sport equipment used by children. Historical experience since 1800 shows that increased energy efficiency usually leads to more energy consumption.
2. Economic incentives. European and other governments provide economic incentives such as reduced taxes and funding to those who produce electricity from wind turbines or solar cells.
3. Use market-based incentives such as taxation to encourage reductions. For example, tax the emission of green-house emissions, allowing each user to determine how best to avoid the tax. This is the approach preferred by economists. The market place is almost always wiser than any politician or government, and it can act much faster and more efficiently.

The different approaches have very different costs, and governments often make popular but costly choices.



cost of different ways to cut emissions of carbon dioxide in euros per ton of ca
improvements are the least expensive, and switching from coal to gas for proc
of the most expensive. From The Economist, 3 June 2007 page 9.

6. Water Resources

MATTHEW R. FISHER

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 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.

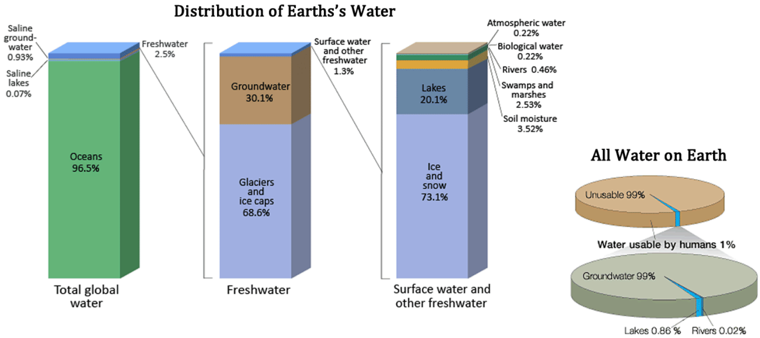


Figure 1. Earth's Water Reservoirs. Bar chart Distribution of Earth's water including total global water, fresh water, and surface water and other fresh water and Pie chart Water usable by humans and sources of usable water. Source: United States Geographical Survey Igor Skiklomanov's chapter "World 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** shows the movement of water through different reservoirs, which include oceans, atmosphere, glaciers, groundwater, lakes, rivers, and biosphere. Solar energy and gravity drive the motion of water in the water cycle. Simply put, the water cycle involves water moving from oceans, rivers, and lakes to the atmosphere by evaporation, forming clouds. From clouds, it falls as precipitation (rain and snow) on both water and land. The water on land can either return to the ocean by surface runoff, rivers, glaciers, and subsurface groundwater flow, or return to the atmosphere by evaporation or **transpiration** (loss of water by plants to the atmosphere).

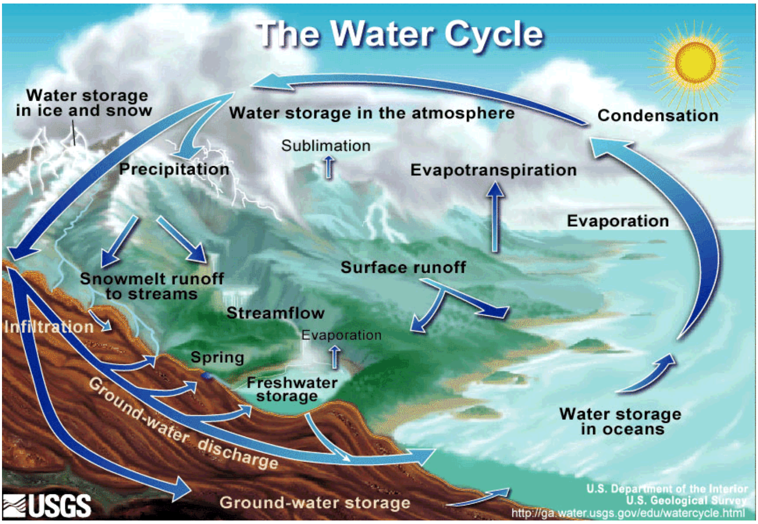


Figure 2. The Water Cycle. Arrows depict movement of water to different reservoirs located above, at, and below Earth's surface. Source: United States Geological Survey

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 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.

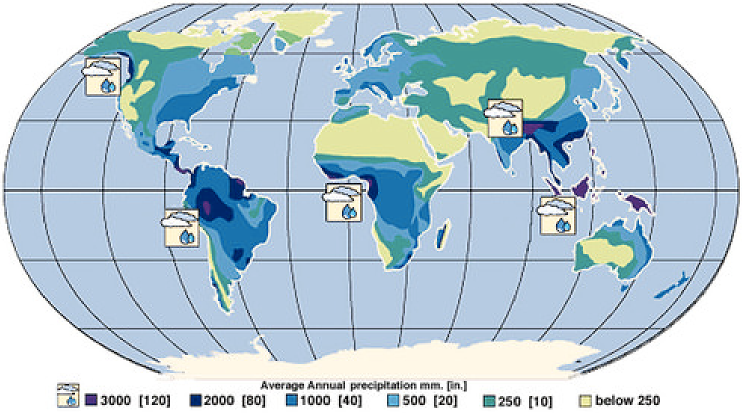


Figure 3. World Rainfall Map. The false-color map above shows the amount of rain that falls around the world. Areas of high rainfall include Central and South America, western Africa, and Southeast Asia. Since these areas receive so much rainfall, they are where most of the world's rainforests grow. 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 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 4) and groundwater seepage (Figure 5). **River discharge** describes the volume of water moving through a river channel over time (Figure 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 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 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.

Although **glaciers** represent the largest reservoir of fresh water, they generally are not used as a water source because they are located too far from most people (Figure 7). Melting glaciers do provide a natural source of river water and groundwater. During the last Ice Age there was as much as 50% more water in glaciers than there is today, which caused sea level to be about 100 m lower. Over the past century, sea level has been rising in part due to melting glaciers. If Earth's climate continues to warm, the melting glaciers will cause an additional rise in sea level.

Figure 7. Mountain Glacier in Argentina Glaciers are the largest reservoir of fresh water but they are not used much as a water resource directly by society because of their distance from most people. Source: Luca Galuzzi – www.galuzzi.it

Groundwater Resources

Although most people in the world use surface water, groundwater is a much larger reservoir of usable fresh water, containing more than 30 times more water than rivers and lakes combined. Groundwater is a particularly important resource in arid climates, where surface water may be scarce. In addition, groundwater is the primary water source for rural homeowners, providing 98% of that water demand in the U.S.. **Groundwater** is water located in small spaces, called **pore space**, between mineral grains and fractures in subsurface earth materials (rock or sediment). Most groundwater originates from rain or snowmelt, which infiltrates the ground and moves downward until it reaches the **saturated zone** (where groundwater completely fills pore spaces in earth materials).

Other sources of groundwater include seepage from surface water (lakes, rivers, reservoirs, and swamps), surface water deliberately pumped into the ground, irrigation, and underground wastewater treatment systems (septic tanks). **Recharge areas** are locations where surface water infiltrates the ground rather than running into rivers or evaporating. Wetlands, for example, are excellent recharge areas. A large area of sub-surface, porous rock that holds water is an aquifer. Aquifers are commonly drilled, and wells installed, to provide water for agriculture and personal use.

Water Use in the U.S. and World

People need water, oftentimes large quantities, to produce the food, energy, and mineral resources they use. Consider, for example, these approximate water requirements for some things people in the developed world use every day: one tomato = 3 gallons; one kilowatt-hour of electricity from a thermoelectric power plant = 21 gallons; one loaf of bread = 150 gallons; one pound of beef = 1,600 gallons; and one ton of steel = 63,000 gallons. Human beings require only about 1 gallon per day to survive, but a typical person in a U.S. household uses approximately 100 gallons per day, which includes cooking, washing dishes and clothes, flushing the toilet, and bathing. The **water demand** of an area is a function of the population and other uses of water.

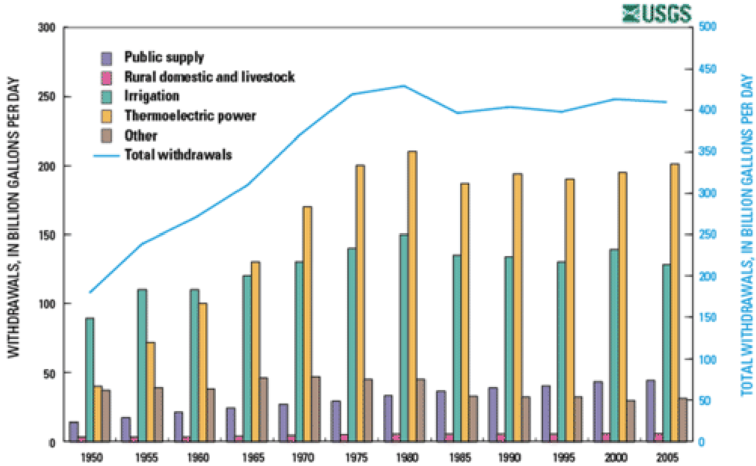


Figure 8. Trends in Total Water Withdrawals by Water-use Category, 1950-2005 Trends in total water withdrawals in the U.S. from 1950 to 2005 by water use category, including bars for thermoelectric power, irrigation, public water supply, and rural domestic and livestock. Thin blue line represents total water withdrawals using vertical scale on right. Source: United States Geological Survey

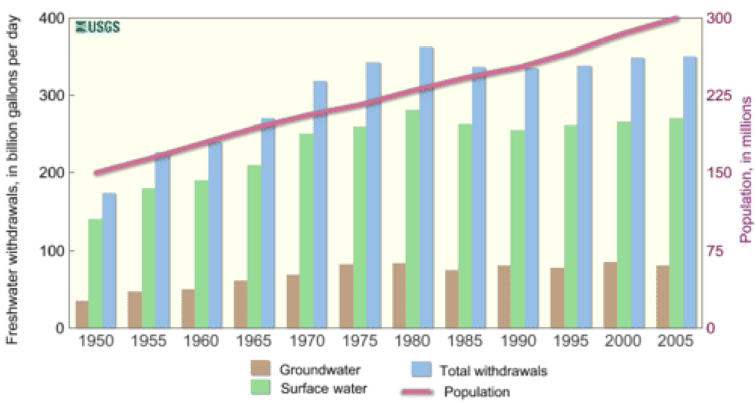


Figure 9. Trends in Source of Fresh Water Withdrawals in the U.S. from 1950 to 2005 Trends in source of fresh water withdrawals in the U.S. from 1950 to 2005, including bars for surface water, groundwater, and total water. Red line gives U.S. population using vertical scale on right. Source: United States Geological Survey

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

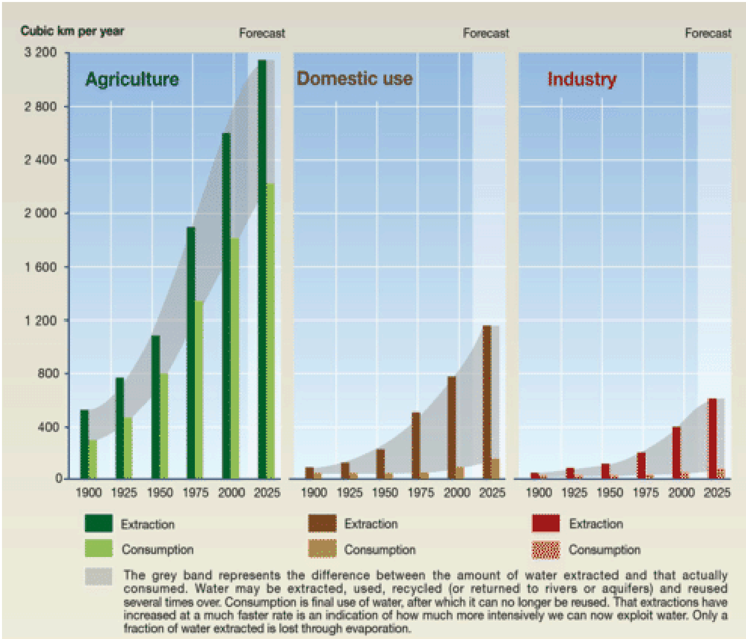


Figure 10. Trends in World Water Use from 1900 to 2000 and Projected to 2025 For each water major use category, including trends for agriculture, domestic use, and industry. Darker colored bar represents total water extracted for that use category and lighter colored bar represents water consumed (i.e., 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

Water Supply Problems and Solutions

Water Supply Problems: Resource Depletion

As groundwater is pumped from water wells, there usually is a localized drop in the water table around the well called a cone of depression. When there are a large number of wells that have been pumping water for a long time, the regional water table can drop significantly. This is called ***groundwater mining****, which can force the* *drilling of deeper, more expensive wells that commonly encounter more saline groundwater. Rivers, lakes, and artificial lakes (reservoirs) can also be depleted due to overuse. Some large rivers, such as the Colorado in the U.S. and Yellow in China, run dry in some years. The case history of the Aral Sea discussed later in this chapter involves depletion of a lake. Finally, glaciers are being depleted due to accelerated melting associated with global warming over the past century.*

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.*

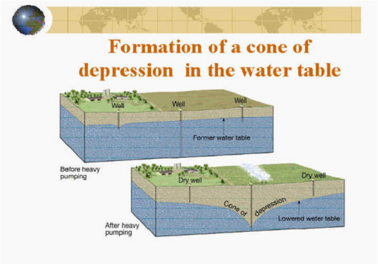


Figure 1. Formation of a Cone of Depression around a Pumping Water Well Source: Fayette County Groundwater Conservation District, TX

Water Supply Crisis

The ***water crisis*** *refers to a global situation where people in many areas lack access to sufficient water, clean water, or both. This section describes the global situation involving water shortages, also called* ***water stress****. In general, water stress is greatest in areas with very low precipitation (major deserts), large population density (e.g., India), or both. Future global warming could worsen the water crisis by shifting precipitation patterns away from humid areas and by melting mountain glaciers that recharge rivers downstream. Melting glaciers will also contribute to rising sea level, which will worsen saltwater intrusion in aquifers near ocean coastlines.*

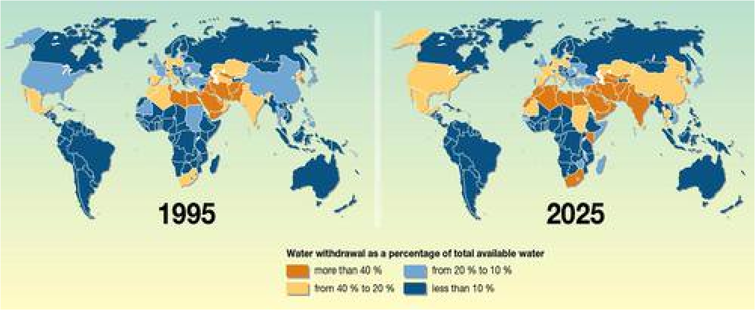


Figure 2. Countries Facing Water Stress in 1995 and Projected in 2025 Water stress is defined as having a high percentage of water withdrawal compared to total available water in the area. Source: Philippe Rekacewicz (Le Monde diplomatique), February 2006

According to a 2006 report by the United Nations Development Programme, 700 million people (11% of the world's population) lived with water stress. Most of them live in the Middle East and North Africa. By 2025, the report projects that more than 3 billion people (about 40% of the world's population) will live in water-stressed areas with the large increase coming mainly from China and India. The water crisis will also impact food production and our ability to feed the ever-growing population. We can expect future global tension and even conflict associated with water shortages and pollution. Historic and future areas of water conflict include the Middle East (Euphrates and Tigris River conflict among Turkey, Syria, and Iraq; Jordan River conflict among Israel, Lebanon, Jordan, and the Palestinian territories), Africa (Nile River conflict among Egypt, Ethiopia, and Sudan), Central Asia (Aral Sea conflict among Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan), and south Asia (Ganges River conflict between India and Pakistan).

Sustainable Solutions to the Water Supply Crisis?

The current and future water crisis described above requires multiple approaches to extending our fresh water supply and moving towards sustainability. Some of the longstanding traditional approaches include dams and aqueducts.

Reservoirs *that form behind dams in rivers can collect water during wet times and store it for use during dry spells. They also can be used for urban water supplies. Other benefits of dams and reservoirs are hydroelectricity, flood control, and recreation. Some of the drawbacks are evaporative loss of water in arid climates, downstream river channel erosion, and impact on the ecosystem including a change from a river to lake habitat and interference with migration and spawning of fish.*

Figure 3. Hoover Dam, Nevada, U.S. Hoover Dam, Nevada, U.S.. Behind the dam is Lake Mead, the largest reservoir in U.S.. White band reflects the lowered water levels in the reservoir due to drought conditions from 2000 – 2010. Source: Cygnusloop99 at Wikimedia Commons

Aqueducts *can move water from where it is plentiful to where it is needed. Aqueducts can be controversial and politically difficult especially if the water transfer distances are large. One drawback is the water diversion can cause drought in the area from where the water is drawn. For example, Owens Lake and Mono Lake in central California began to disappear after their river flow was diverted to the Los Angeles aqueduct. Owens Lake remains almost completely dry, but Mono Lake has recovered more significantly due to legal intervention.*

One method that can actually increase the amount of fresh water on Earth is ***desalination****, which involves removing dissolved salt from seawater or saline groundwater. There are several ways to desalinate seawater including boiling, filtration, and electrodialysis. All of these procedures are moderately to very expensive and require considerable energy input, making the water produced much more expensive than fresh water from conventional sources. In addition, the process creates highly saline wastewater, which must be disposed of and creates significant environmental impact. Desalination is most common in the Middle East, where energy from oil is abundant but water is scarce.*

***Conservation** means using less water and using it more efficiently. Around the home, conservation can involve both engineered features, such as high-efficiency clothes washers and low-flow showers and toilets, as well as behavioral decisions, such as growing native vegetation that require little irrigation in desert climates, turning off the water while you brush your teeth, and fixing leaky faucets.*

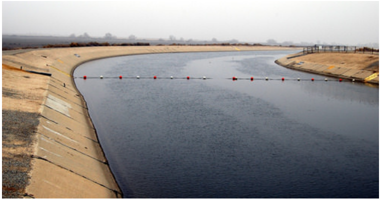


Figure 4. The California Aqueduct California Aqueduct in southern California, U.S. Source: David Jordan at en.wikipedia

***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.*

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 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.

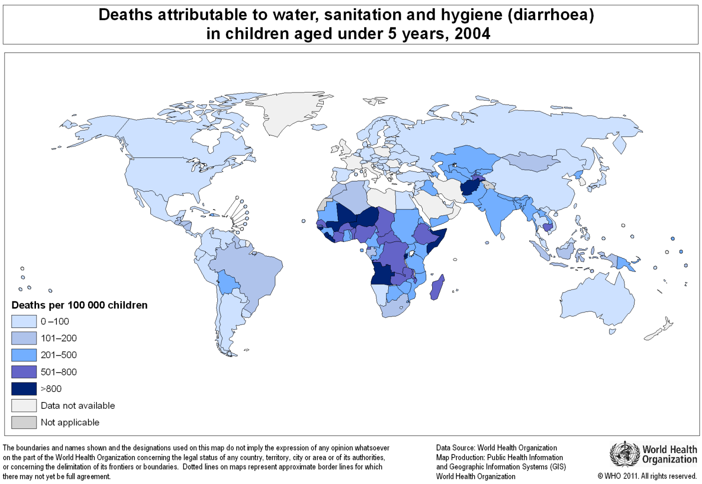


Figure 1. This work was created by the World Health Organization.

*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

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

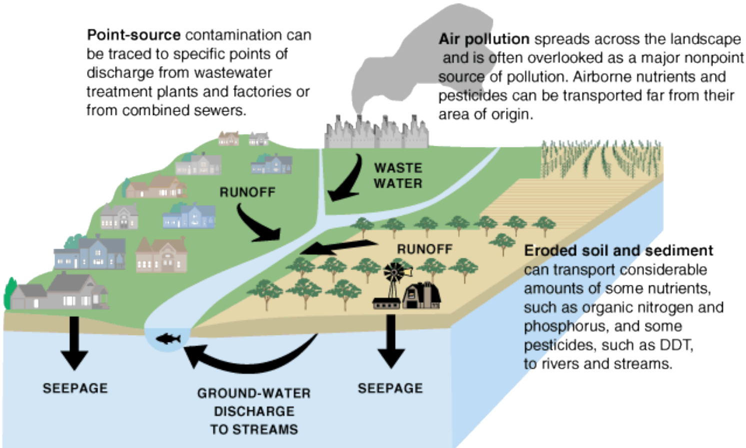


Figure 3. Sources of Water Contamination. Sources of some water pollutants and movement of pollutants into different water reservoirs of the water cycle. Source: U.S. Geological Survey

Figure 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

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 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 5).*

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.*

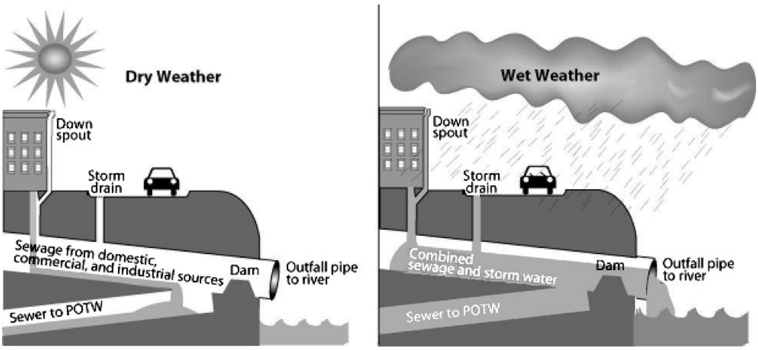


Figure 5. Combined Sewer System A combined sewer system is a possible major point source of water pollution during heavy rain due to overflow of untreated sewage. During dry weather (and small storms), all flows are handled by the publicly owned treatment works (POTW). During large storms, the relief structure allows some of the combined stormwater and sewage to be discharged untreated to an adjacent water body. Source: U.S. Environmental Protection Agency at Wikimedia Commons

Types of Water Pollutants

Oxygen-demanding waste *is an extremely important pollutant to ecosystems. Most surface water in contact with the atmosphere has a small amount of dissolved oxygen, which is needed by aquatic organisms for cellular respiration. Bacteria decompose dead organic matter and remove dissolved oxygen (O_2) according to the following reaction:*

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

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 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 6. Deepwater Horizon Explosion Boats fighting the fire from an explosion at the Deepwater Horizon drilling rig in Gulf of Mexico offshore Louisiana on April 20, 2010. Source: United States Coast Guard via Wikimedia Commons

*During an oil spill on water, oil floats to the surface because it is less dense than water, and the lightest hydrocarbons evaporate, decreasing the size of the spill but polluting the air. Then, bacteria begin to decompose the remaining oil, in a process that can take many years. After several months only about 15% of the original volume may remain, but it is in thick asphalt lumps, a form that is particularly harmful to birds, fish, and shellfish. Cleanup operations can include skimmer ships that vacuum oil from the water surface (effective only for small spills), controlled burning (works only in early stages before the light, ignitable part evaporates but also pollutes the air), **dispersants** (detergents that break up oil to accelerate its decomposition, but some dispersants may be toxic to the ecosystem), and bioremediation (adding microorganisms that specialize in quickly decomposing oil, but this can disrupt the natural ecosystem).*

*Toxic chemicals involve many different kinds and sources, primarily from industry and mining. General kinds of toxic chemicals include hazardous chemicals and persistent organic pollutants that include DDT (pesticide), dioxin (herbicide by-product), and PCBs (polychlorinated biphenyls, which were used as a liquid insulator in electric transformers). **Persistent organic pollutants** (POPs) are long-lived in the environment, biomagnify through the food chain, and can be toxic. Another category of toxic chemicals includes radioactive materials such as cesium, iodine, uranium, and radon gas, which can result in long-term exposure to radioactivity if it gets into the body. A final group of toxic chemicals is heavy metals such as lead, mercury, arsenic, cadmium, and* *chromium, which can accumulate through the food chain. Heavy metals are commonly produced by industry and at metallic ore mines. Arsenic and mercury are discussed in more detail below.*

Arsenic (As) has been famous as an agent of death for many centuries. Only recently have scientists recognized that health problems can be caused by drinking small arsenic concentrations in water over a long time. It enters the water supply naturally from weathering of arsenic-rich minerals and from human activities such as coal burning and smelting of metallic ores. The worst case of arsenic poisoning occurred in the densely populated impoverished country of Bangladesh, which had experienced 100,000s of deaths from diarrhea and cholera each year from drinking surface water contaminated with pathogens due to improper sewage treatment. In the 1970s the United Nations provided aid for millions of shallow water wells, which resulted in a dramatic drop in pathogenic diseases. Unfortunately, many of the wells produced water naturally rich in arsenic. Tragically, there are an estimated 77 million people (about half of the population) who inadvertently may have been exposed to toxic levels of arsenic in Bangladesh as a result. The World Health Organization has called it the largest mass poisoning of a population in history.

Mercury (Hg) is used in a variety of electrical products, such as dry cell batteries, fluorescent light bulbs, and switches, as well as in the manufacture of paint, paper, vinyl chloride, and fungicides. Mercury acts on the central nervous system and can cause loss of sight, feeling, and hearing as well as nervousness, shakiness, and death. Like arsenic, mercury enters the water supply naturally from weathering of mercury-rich minerals and from human activities such as coal burning and metal processing. A famous mercury poisoning case in Minamata, Japan involved methylmercury-rich industrial discharge that caused high Hg levels in fish. People in the local fishing villages ate fish up to three times per day for over 30 years, which resulted in over 2,000 deaths. During that time the responsible company and national government did little to mitigate, help alleviate, or even acknowledge the problem.

***Hard water** contains abundant calcium and magnesium, which reduces its ability to develop soapsuds and enhances scale (calcium and magnesium carbonate minerals) formation on hot water equipment. Water softeners remove calcium and magnesium, which allows the water to lather easily and resist scale formation. Hard water develops naturally from the dissolution of calcium and magnesium carbonate minerals in soil; it does not have negative health effects in people.*

***Groundwater pollution** can occur from underground sources and all of the pollution sources that contaminate surface waters. Common sources of groundwater pollution are leaking underground storage tanks for fuel, septic tanks, agricultural activity, landfills, and fossil fuel extraction. Common groundwater pollutants include nitrate, pesticides, volatile organic compounds, and petroleum products. Another troublesome feature of groundwater pollution is that small amounts of certain pollutants, e.g., petroleum products and organic* *solvents, can contaminate large areas. In Denver, Colorado 80 liters of several organic solvents contaminated 4.5 trillion liters of groundwater and produced a 5 km long contaminant plume. A major threat to groundwater quality is from underground fuel storage tanks. Fuel tanks commonly are stored underground at gas stations to reduce explosion hazards. Before 1988 in the U.S. these storage tanks could be made of metal, which can corrode, leak, and quickly contaminate local groundwater. Now, leak detectors are required and the metal storage tanks are supposed to be protected from corrosion or replaced with fiberglass tanks. Currently there are around 600,000 underground fuel storage tanks in the U.S. and over 30% still do not comply with EPA regulations regarding either release prevention or leak detection.*

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 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.*

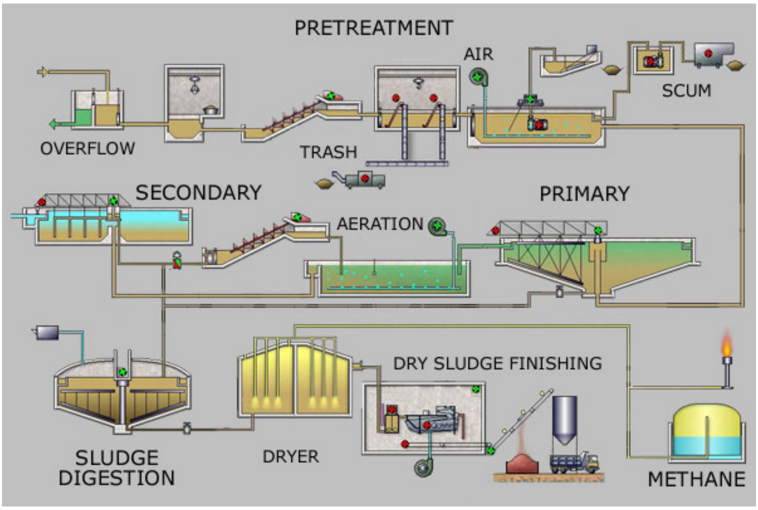


Figure 1. Steps at a Sewage Treatment Plant The numerous processing steps at a conventional sewage treatment plant include pretreatment (screening and removal of sand and gravel), primary treatment (settling or floatation to remove organic solids, fat, and grease), secondary treatment (aerobic bacterial 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 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.*

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.

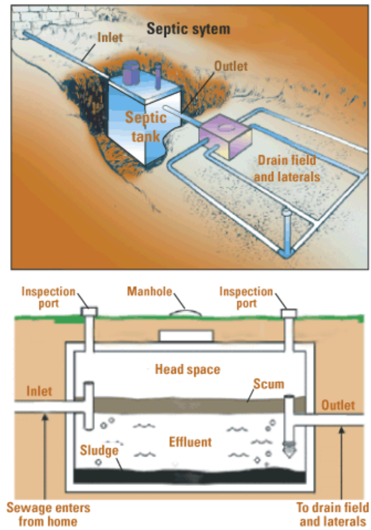


Figure 2. Septic System Septic tank system for sewage treatment. Source: United States Geological Survey

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 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.*

7. Solid and Hazardous Waste

SILPA KAZA, LISA YAO, PERINAZ BHADA-TATA, AND FRANK VAN WOERDEN

At a Glance: A Global Picture of Solid Waste Management

Key Insights:

• The world generates 0.74 kilogram of waste per capita per day, yet national waste generation rates fluctuate widely from 0.11 to 4.54 kilograms per
capita per day. Waste generation volumes are generally correlated with income levels and urbanization rates.
• An estimated 2.01 billion tonnes of municipal solid waste were generated in 2016, and this number is expected to grow to 3.40 billion tonnes by
2050 under a business-as-usual scenario.
• The total quantity of waste generated in low-income countries is expected to increase by more than three times by 2050. Currently, the East Asia and
Pacific region is generating most of the world's waste, at 23 percent, and the Middle East and North Africa region is producing the least in absolute
terms, at 6 percent. However, waste is growing the fastest in Sub-Saharan Africa, South Asia, and the Middle East North Africa regions, where, by
2050, total waste generated is expected to approximately triple,

double, and double, respectively.

• Food and green waste comprise more than 50 percent of waste in low- and middle-income countries. In high-income countries the amount of organic waste is comparable in absolute terms but, because of larger amounts of packaging waste and other nonorganic waste, the fraction of organics is about 32 percent.

• Recyclables make up a substantial fraction of waste streams, ranging from 16 percent paper, cardboard, plastic, metal, and glass in low-income countries to about 50 percent in high-income countries. As countries rise in income level, the quantity of recyclables in the waste stream increases, with paper increasing most significantly.

• Waste collection rates vary widely by income levels. High- and upper-middle income countries typically provide universal waste collection. Low-income countries tend to collect about 48 percent of waste in cities, but outside of urban areas waste collection coverage is about 26 percent. In middle income countries, rural waste collection coverage varies from 33 percent to 45 percent.

• Globally, about 37 percent of waste is disposed of in some type of landfill, 33 percent is openly dumped, 19 percent undergoes materials recovery through recycling and composting, and 11 percent is treated through modern incineration.

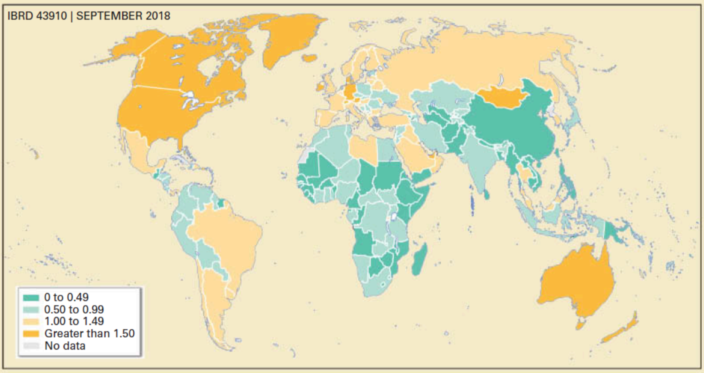
• Adequate waste disposal or treatment using controlled landfills or more stringently operated facilities is almost exclusively the domain of high and upper-middle-income countries. Lower-income countries generally rely on open dumping—93 percent of waste is dumped in low-income countries and only 2 percent in high-income countries.

• Upper-middle-income countries practice the highest percentage of landfilling, at 54 percent. This rate decreases in high-income countries to
39 percent, where 35 percent of waste is diverted to recycling and composting and 22 percent to incineration.

Waste Generation

Waste generation is a natural product of urbanization, economic development, and population growth. As nations and cities become more
populated and prosperous, offer more products and services to citizens, and participate in global trade and exchange, they face corresponding amounts
of waste to manage through treatment and disposal (map 2.1). The 2012 edition of What a Waste: A Global Review of Solid Waste Management estimated global waste production to be 1.3 billion tonnes per year based on available data (Hoornweg and Bhada-Tata 2012). In recent years, waste production has grown at levels consistent with initial projections, and data tracking and reporting have improved substantially. Based on the latest data available, global waste generation in 2016 was estimated
to have reached 2.01 billion tonnes. Countries in the East Asia and Pacific and the Europe and Central Asia regions account for 43 percent of the world's waste by magnitude (figure 2.1, panel a). The Middle East and North Africa and Sub-Saharan Africa regions produce the least amount of waste, together accounting for 15 percent of the
world's waste. East Asia and Pacific generates the most in absolute terms, an estimated 468 million tonnes in 2016, and the Middle East and North Africa
region generates the least, at 129 million tonnes (figure 2.1, panel b).

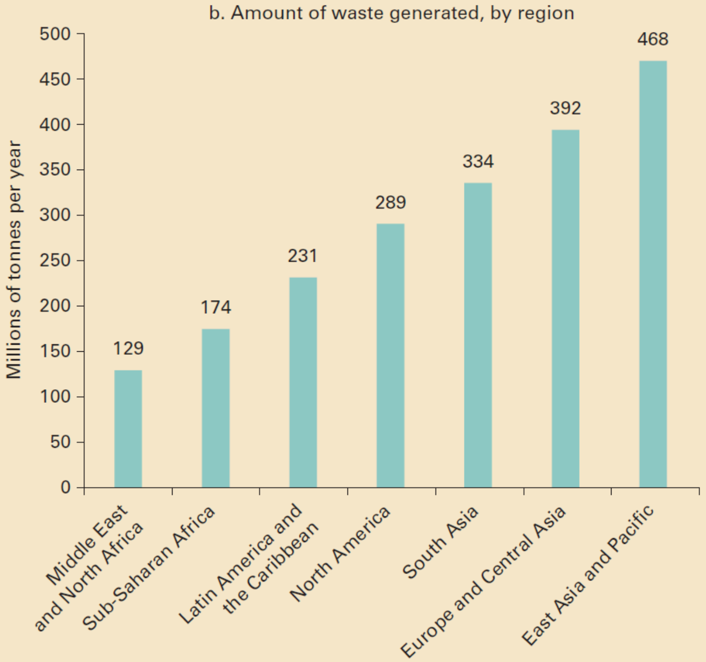
Map 2.1 Waste Generation Per Capita



Note: kg = kilogram.

Although they only account for 16 percent of the world's population, high-income countries generate 34 percent, or 683 million tonnes, of the
world's waste (figure 2.2). Low-income countries account for 9 percent of the world's population but generate only about 5 percent of global waste,
or 93 million tonnes. The three countries in the North America region—Bermuda, Canada, and the United States—produce the highest average amount of waste per capita,
at 2.21 kilograms per day. All three countries are high-income nations. The three regions with a high proportion of low- and middle-income nations generate
the lowest amount of waste per capita: Sub-Saharan Africa averages 0.46 kilogram per day, South Asia 0.52 kilogram per day, and East Asia and
Pacific 0.56 kilogram per day. Overall, the estimated global average for 2016 is 0.74 kilogram of waste per capita per day and total generation of solid
waste is about 2.01 billion tonnes.

Figure 2.1 Waste Generation by Region *(continued)*



Note: Data adjusted to 2016.

Waste Composition

Waste composition is the categorization of types of materials in municipal solid waste. Waste composition is generally determined through a
standard waste audit, in which samples of garbage are taken from generators or final disposal sites, sorted into predefined categories, and
weighed. At an international level, the largest waste category is food and green waste, making up 44 percent of global waste (figure 2.8). Dry recyclables
(plastic, paper and cardboard, metal, and glass) amount to

another 38 percent of waste. Waste composition varies considerably by income level (figure 2.9). The percentage of organic matter in waste decreases as income levels rise. Consumed goods in higher-income countries include more materials such as paper and plastic than they do in lower-income countries. The granularity of data for waste composition, such as detailed accounts of rubber and wood waste, also increases by income level.

Figure 2.8 Global Waste Composition
percent

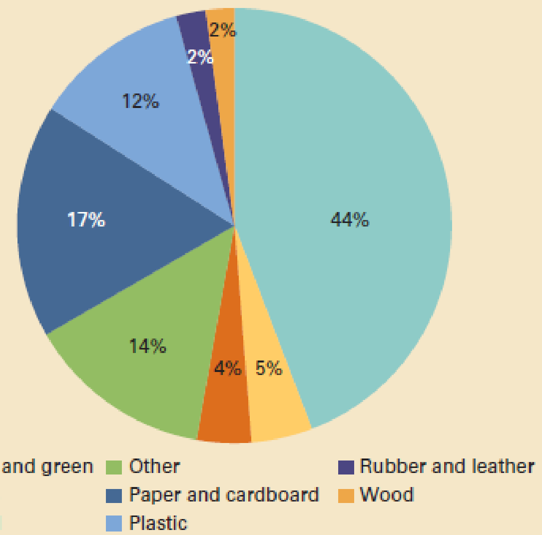
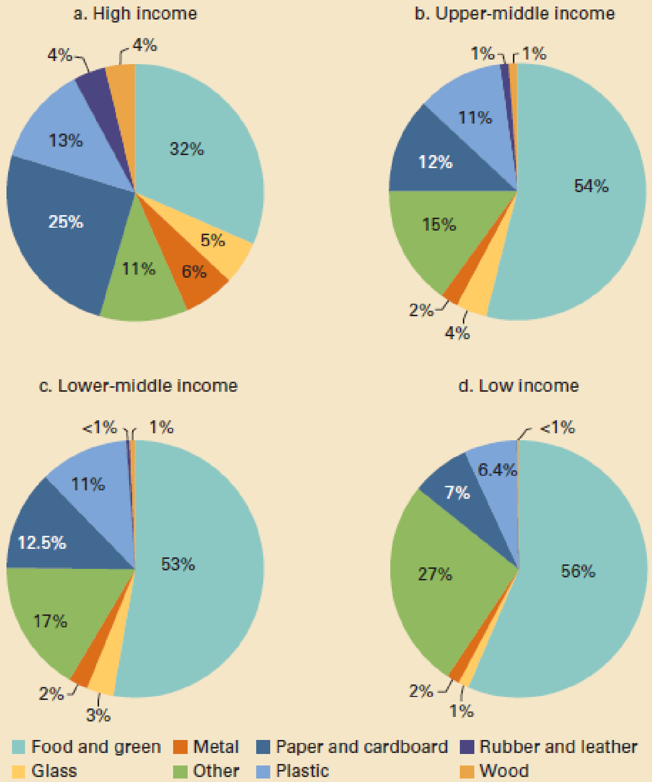


Figure 2.9 **Waste Composition by Income Level**
percent



Global Food Loss and Waste

Across global food systems, food loss and waste (FLW) is a widespread issue, posing a challenge to food security, food safety, the economy, and environmental sustainability. No accurate estimates of the extent of FLW are available, but studies indicate that FLW is roughly 30 percent of all food

globally (FAO 2015). This amounts to 1.3 billion tonnes per year. FLW represents wastage of resources, including the land, water, labor, and energy used to produce food. It strongly contributes to climate change because greenhouse gases are emitted during food production and distribution activities, and methane is released during the decay of wasted food. FLW also affects food supply chains by lowering income for food producers, increasing costs for food consumers, and reducing access to food. Minimizing FLW could lead to substantial food security
and environmental gains. The causes of FLW vary across the world and depend on specific local conditions. Typically, FLW in low-income countries occurs at the production, postharvest handling, storage, and processing stages and is caused predominantly by managerial and technical limitations. FLW mostly occurs in the distribution and consumption stages in middle- and high-income countries, although it can happen in earlier stages such as when agricultural subsidies lead to overproduction
of farm crops. These challenges relate to consumer behavior and government policies and regulation.

Improving coordination among actors along the different stages of the supply chain could address some of the FLW issues globally. Measures to reduce FLW in low-income countries could involve investment in infrastructure and transportation, including in technology for storage and cooling. Small-scale farmers could also be supported by provision of improved financing and credit to allow them to diversify or scale their production. In high-income countries, consumer education for behavior change is key to decreasing FLW. In addition to decreasing FLW along the supply chain, discarded food could also be managed productively for composting and energy recovery.

Regional and international stakeholders are taking action to address FLW. The African Union is working with 14

governments to translate the "Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods," including food loss reduction, into proper national policy and strategies in Africa (African Union Commission 2014). The Deputy-Secretary General of the United Nations called on all partners to adopt a more holistic
approach to food security, one that prioritizes FLW, builds new coalitions, scales up current work, and innovates (Helvetas 2018). The Food and Agriculture Organization has been working on developing new metrics and methodologies to measure FLW, and the organization's SAVE FOOD Initiative works with civil society to address the issue (FAO 2018). The World Food Programme is including food loss as part of some five-year country plans in Africa and launched the Farm to Market Alliance
to structure local markets and promote loss reduction technologies among smallholder farmers (World Food Program 2017). The World Bank is tackling the issue through loans, such as in Argentina, and by coordinated food waste management and the establishment of a cross-sectoral strategy (World Bank 2015).

Several national and local governments have also taken action. In 2016, the government of Italy approved a law to enhance collaboration among key stakeholders, educate the public, encourage food donations from business through financial incentives, and promote reusable and recyclable packaging (Azzuro, Gaiani, and Vittuari 2016). In 2016, France became the first country in the world to ban supermarkets from throwing away or destroying unsold food, forcing them instead to donate
it to charities and food banks (Chrisafis 2016). In 2009, the city of San Francisco in the United States passed an ordinance requiring all residents and tourists to compost food waste (McClellan 2017). The city of Ningbo in China diverts food waste

from apartment buildings to an anaerobic digestion facility (Lee et al. 2014). In several cities in Sweden, biogas is produced from food waste to power vehicles and generate heat (Swedish Gas Centre, Swedish Gas Association, and Swedish Biogas Association 2008). In cities like Linköping, Sweden, the majority of public buses have been converted to use recovered biogas. The optimal strategy to reduce loss and recover food waste depends greatly on the local context, but the increasing global action reveals the many policy, technology, and educational avenues available.

Waste Collection

Waste collection is one of the most common services provided at a municipal level. Several waste collection service models are used across the globe. The most common form of waste collection is door-to-door collection. In this model, trucks or small vehicles—or, where environments are more constrained, handcarts or donkeys—are used to pick up garbage outside of households at a predetermined frequency. In certain localities, communities may dispose of waste in a central container or collection point where it is picked up by the municipality and transported to final disposal sites. In other areas with less regular collection, communities may be notified through a bell or other signal that a collection vehicle has arrived in the neighborhood, such as in Taiwan, China. Waste collection rates in high-income countries and in North America are near 100 percent. In lower-middle-income countries, collection rates are about 51 percent, and in low-income countries, about 39 percent. In low-income countries,

uncollected waste is often managed independently by households and may be openly dumped, burned, or, less commonly, composted. Improvement of waste collection services is
a critical step to reduce pollution and thereby to improve human health and, potentially, traffic congestion. Waste collection rates tend to be substantially higher for urban areas than for rural areas, since waste management is typically an urban service. In lower-middle-income countries, waste collection rates are more than
twice as high in cities as in rural areas.

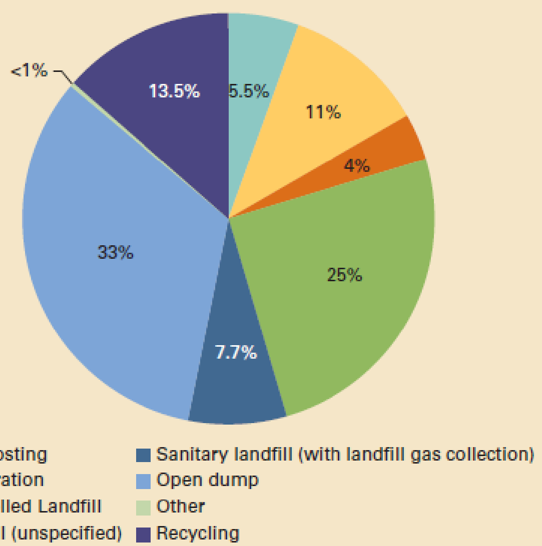
Waste Disposal

Around the world, almost 40 percent of waste is disposed of in landfills (figure 2.12).3 About 19 percent undergoes materials recovery through
recycling and composting,4 and 11 percent is treated through modern incineration. Although globally 33 percent of waste is still openly
dumped, governments are increasingly recognizing the risks and costs of dumpsites and pursuing sustainable waste disposal methods.
Waste disposal practices vary significantly by income level and region. Open dumping is prevalent in lower-income countries, where landfills are not yet available. About 93 percent of waste is burned or dumped in roads, open land, or waterways in low-income countries,
whereas only 2 percent of waste is dumped in high-income countries. More than two-thirds of waste is dumped in the South Asia and Sub-
Saharan Africa regions, which will significantly impact future waste growth. As nations prosper economically, waste is managed using more sustainable

methods. Construction and use of landfills is commonly the first step toward sustainable waste management. Whereas only 3 percent of waste is deposited in landfills in low-income countries, about 54 percent of waste is sent to landfills in upper-middle-income countries. Furthermore, wealthier countries tend to put greater focus on materials recovery through recycling and composting. In high-income countries, 29 percent of waste is recycled and 6 percent composted. Incineration is also more common. In high income countries, 22 percent of waste is incinerated, largely within high capacity and land-constrained countries and territories such as Japan and

the British Virgin Islands.

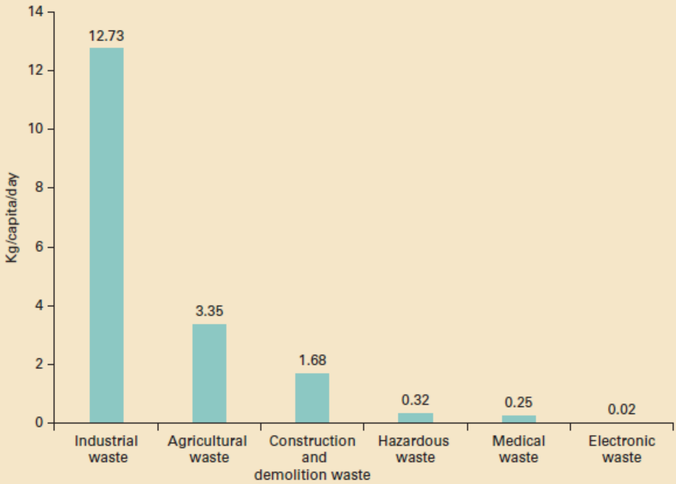
Figure 2.12 Global Waste Treatment and Disposal
percent



Special Wastes

Municipal solid waste is one of several waste streams that countries and cities manage. Other common waste streams include industrial waste,
agricultural waste, construction and demolition waste, hazardous waste, medical waste, and electronic waste, or e-waste (figure 2.14). Some waste streams, such as industrial waste, are generated in much higher quantities than municipal solid waste. For the countries with available industrial waste generation data, the trend shows that globally, industrial waste generation is almost 18 times greater than municipal solid waste. Generation of industrial waste rises significantly as income level increases.
Global agricultural waste production is more than four and a half times that of municipal solid waste. Agricultural waste is most significant in countries
with large farming industries. Agricultural waste is often managed separately from other waste streams since it is largely organic and may serve
as a useful input for future agricultural activities. Construction and demolition waste may compete with municipal solid waste for disposal space in landfills. In some countries, such as India, it is common to dispose of both in the same disposal facilities. Hazardous, medical, and e-waste are typically only a fraction of municipal solid waste. If disposed of properly, these wastes are typically treated in specialized facilities, including chemical processing plants, incinerators, and disassembly centers, respectively. The generation of e-waste is associated with economic development, with high-income countries generating five times the volume of e-waste generated by lower middle-income countries. The increasing amount of e-waste and its potential for environmental pollution and recycling may be an area of
consideration for rapidly developing countries.

Figure 2.14 **Global Average Special Waste Generation**



Note: kg = kilogram.

8. Importance of Biodiversity

MATTHEW R. FISHER

The Biodiversity Crisis

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

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.

Figure 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 like the one pictured in Figure 1, which are very high in biodiversity but are being cleared for timber and agriculture. This is likely to have dramatic effects on human welfare through the collapse of ecosystems.

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

Types of Biodiversity

A common meaning of biodiversity is simply the number of species in a location or on Earth; for example, the American Ornithologists' Union lists 2078 species of birds in North and Central America. This is one measure of the bird biodiversity on the continent. More sophisticated measures of diversity take into account the relative abundances of species. For example, a forest with 10 equally common species of trees is more diverse than a forest that has 10 species of trees wherein just one of those species makes up 95 percent of the trees. Biologists have also identified alternate measures of biodiversity, some of which are important in planning how to preserve biodiversity.

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

It is also useful to define **ecosystem diversity**: the number of different ecosystems on Earth or in a geographical area. The loss of an ecosystem means the loss of the interactions between species and the loss of biological productivity that an ecosystem is able to create. An example of a largely extinct ecosystem in North America is the prairie ecosystem (Figure 2).

Prairies once spanned central North America from the boreal forest in northern Canada down into Mexico. They are now all but gone, replaced by crop fields, pasture lands, and suburban sprawl. Many of the species survive, but the hugely productive ecosystem that was responsible for creating our most productive agricultural soils is now gone. As a consequence, their soils are now being depleted unless they are maintained artificially at great expense. The decline in soil productivity occurs because the interactions in the original ecosystem have been lost.

Figure 2. The variety of ecosystems on Earth—from coral reef to prairie—enables a great diversity of species to exist. (credit "coral reef": modification of work by Jim Maragos, USFWS; credit: "prairie": modification of work by Jim Minnerath, USFWS)

Current Species Diversity

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

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

Estimated Numbers of Described and Predicted species

	Source: Mora et al 2011		**Source: Chapman 2009**		**Source: Groo and Jenkins**	
	Described	Predicted	Described	Predicted	Described	P
Animals	1,124,516	9,920,000	1,424,153	6,836,330	1,225,500	1
Photosynthetic protists	17,892	34,900	25,044	200,500	—	–
Fungi	44,368	616,320	98,998	1,500,000	72,000	1
Plants	224,244	314,600	310,129	390,800	270,000	3
Non-photosynthetic protists	16,236	72,800	28,871	1,000,000	80,000	6
Prokaryotes	—	—	10,307	1,000,000	10,175	–
Total	1,438,769	10,960,000	1,897,502	10,897,630	1,657,675	1

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

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

Patterns of Biodiversity

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

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

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

There are three main fields of study under the heading of biogeography: ecological biogeography, historical biogeography (called paleobiogeography), and conservation biogeography. Ecological biogeography studies the current factors affecting the distribution of plants and animals. Historical biogeography, as the name implies, studies the past distribution of species. Conservation biogeography, on the other hand, is focused on the protection and restoration of species based upon the known historical and current ecological information.

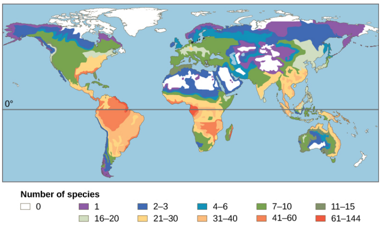


Figure 3. This map illustrates the number of amphibian species across the globe and shows the trend toward higher biodiversity at lower latitudes. A similar pattern is observed for most taxonomic groups.

One of the oldest observed patterns in ecology is that biodiversity typically increases as latitude declines. In other words, biodiversity increases closer to the equator (Figure 3).

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

Importance of Biodiversity

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

Human Health

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

Modern pharmaceutical science also recognizes the importance of these plant compounds. Examples of significant medicines derived from plant compounds include aspirin, codeine, digoxin, atropine, and vincristine (Figure 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.

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.

Figure 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)

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

Finally, it has been argued that humans benefit psychologically from living in a biodiverse world. The chief proponent of this idea is famed entomologist E. O. Wilson. He argues that human evolutionary history has adapted us to living in a natural environment and that built environments generate stresses that affect human health and well-being.

There is considerable research into the psychologically regenerative benefits of natural landscapes that suggest the hypothesis may hold some truth.

Agricultural

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

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

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

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

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

Figure 5. The Svalbard Global Seed Vault is a storage facility for seeds of Earth's diverse crops. (credit: Mari Tefre, Svalbard Global Seed Vault)

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

Finally, humans compete for their food with crop pests, most of which are insects. Pesticides control these competitors, but these are costly and lose their effectiveness over time as pest populations adapt. They also lead to collateral damage by killing non-pest species as well as beneficial insects like honeybees, and risking the health of agricultural workers and consumers. Moreover, these pesticides may migrate from the fields where they are applied and do damage to other ecosystems like streams, lakes, and even the ocean. Ecologists believe that the bulk of the work in removing pests is actually done by predators and parasites of those pests, but the impact has not been well studied. A review found that in 74 percent of studies that looked for an effect of landscape complexity (forests and fallow fields near to crop fields) on natural enemies of pests, the greater the complexity, the greater the effect of pest-suppressing organisms. Another experimental study found that introducing multiple enemies of pea aphids (an important alfalfa pest) increased the yield of alfalfa significantly. This study shows that a diversity of pests is more effective at control than one single pest. Loss of diversity in pest enemies will inevitably make it more difficult and costly to grow food. The world's growing human population faces significant challenges in the increasing costs and other difficulties associated with producing food.

Wild Food Sources

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

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

Threats to Biodiversity

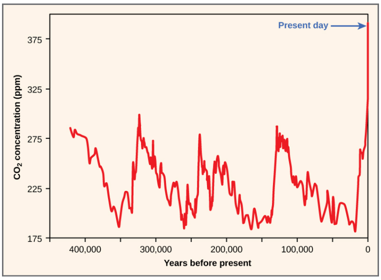


Figure 1. Atmospheric carbon dioxide levels fluctuate in a cyclical manner. However, the burning of fossil fuels in recent history has caused a dramatic increase in the levels of carbon dioxide in the Earth's atmosphere, which have now reached levels never before seen on Earth. Scientists predict that the addition of this "greenhouse gas" to the atmosphere is resulting in climate change that will significantly impact biodiversity in the coming century.

The core threat to biodiversity on the planet, and therefore a threat to human welfare, is the combination of human population growth and the resources used by that population. The human population requires resources to survive and grow, and many of those resources are being removed unsustainably from the environment. The three greatest proximate threats to biodiversity are habitat loss, overharvesting, and introduction of exotic species. The first two of these are a direct result of human population growth and resource use. The third results from increased mobility and trade. A fourth major cause of extinction, **anthropogenic** (human-caused) climate change, has not yet had a large impact, but it is predicted to become significant during this century. Global climate change is also a consequence of human population needs for energy and the use of fossil fuels to meet those needs (Figure 1). Environmental issues, such as toxic pollution, have specific targeted effects on species, but are not generally seen as threats at the magnitude of the others.

Habitat Loss

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

Figure 2. An oil palm plantation in Sabah province Borneo, Malaysia, replaces native forest habitat that a variety of species depended on to live. (credit: Lian Pin Koh)

Consider the exceptional biodiversity of Sumatra: it is home to one species of orangutan, a species of critically endangered elephant, and the Sumatran tiger, but half of Sumatra's forest is now gone. The neighboring island of Borneo, home to the other species of orangutan, has lost a similar area of forest. Forest loss continues in protected areas of Borneo. The orangutan in Borneo is listed as endangered by the International Union for Conservation of Nature (IUCN), but it is simply the most visible of thousands of species that will not survive the disappearance of the forests of Borneo. The forests are removed for timber and to plant palm oil plantations (Figure 2). Palm oil is used in many products including food products, cosmetics, and biodiesel in Europe. A 5-year estimate of global forest cover loss for the years from 2000 to 2005 was 3.1%. Much loss (2.4%) occurred in the tropics where forest loss is primarily from timber extraction. These losses certainly also represent the extinction of species unique to those areas.

BIOLOGY IN ACTION: Preventing Habitat Destruction with Wise Wood Choices

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

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

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

Overharvesting

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

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

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

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

Figure 3. Harvesting of pangolins for their scales and meat, and as curiosities, has led to a drastic decline in population size for this fascinating creature. This work by David Brossard is licensed under CC BY 4.0

Invasive Species

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

Most exotic species introductions probably fail because of the low number of individuals introduced or poor adaptation to the ecosystem they enter. Some species, however, have characteristics that can make them especially successful in a new ecosystem. These exotic species often undergo dramatic population increases in their new habitat and reset the ecological conditions in the new environment, threatening the species that exist there. When this happens, the exotic species also becomes an **invasive species**. Invasive species can threaten other species through competition for resources, predation, or disease.

Lakes and islands are particularly vulnerable to extinction threats from introduced species. In Lake Victoria, the intentional introduction of the Nile perch was largely responsible for the extinction of about 200 species of cichlids. The accidental introduction of the brown tree snake via aircraft (Figure 4) from the Solomon Islands to Guam in 1950 has led to the extinction of three species of birds and three to five species of reptiles endemic to the island. Several other species are still threatened. The brown tree snake is adept at exploiting human transportation as a means to migrate; one was even found on an aircraft arriving in Corpus Christi, Texas. Constant vigilance on the part of airport, military, and commercial aircraft personnel is required to prevent the snake from moving from Guam to other islands in the Pacific, especially Hawaii. Islands do not make up a large area of land on the globe, but they do contain a disproportionate number of endemic species because of their isolation from mainland ancestors.

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

Figure 4. The brown tree snake, Boiga irregularis, is an exotic species that has caused numerous extinctions on the island of Guam since its accidental introduction in 1950. (credit: NPS)

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 5). There is evidence that the fungus is native to Africa and may have been spread throughout the world by transport of a commonly used laboratory and pet species: the African clawed frog, *Xenopus laevis*. It may well be that biologists themselves are responsible for spreading this disease worldwide. The North American bullfrog, *Rana catesbeiana*, which has also been widely introduced as a food animal but which easily escapes captivity, survives most infections of *B. dendrobatidis* and can act as a reservoir for the disease.

Figure 5. This Limosa harlequin frog (Atelopus limosus), an endangered species from Panama, died from a fungal disease called chytridiomycosis. The red lesions are symptomatic of the disease. (credit: Brian Gratwicke)

Early evidence suggests that another fungal pathogen, *Geomyces destructans*, introduced from Europe is responsible for white-nose syndrome, which infects cave-hibernating bats in eastern North America and has spread from a point of origin in western New York State (Figure 6). The disease has decimated bat populations and threatens extinction of species already listed as endangered: the Indiana bat, *Myotis sodalis*, and potentially the Virginia big-eared bat, *Corynorhinus townsendii virginianus*. How the fungus was introduced is unknown, but one logical presumption would be that recreational cavers unintentionally brought the fungus on clothes or equipment from Europe.

Climate Change

Figure 6. This little brown bat in Greeley Mine, Vermont, March 26, 2009, was found to have white-nose syndrome. (credit: modification of work by Marvin Moriarty, USFWS).

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

The shifting ranges will impose new competitive regimes on species as they find themselves in contact with other species not present in their historic range. One such unexpected species contact is between polar bears and grizzly bears.

Previously, these two species had separate ranges. Now, their ranges are overlapping and there are documented cases of these two species mating and producing viable offspring. Changing climates also throw off the delicate timing adaptations that species have to seasonal food resources and breeding times. Scientists have already documented many contemporary mismatches to shifts in resource availability and timing.

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

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

Figure 7. The effect of global warming can be seen in the continuing retreat of Grinnell Glacier. The mean annual temperature in Glacier National Park has increased 1.33°C since 1900. The loss of a glacier results in the loss of summer meltwaters, sharply reducing seasonal water supplies and severely affecting local ecosystems. (credit: USGS, GNP Archives)

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

Preserving Biodiversity

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

Change in Biodiversity through Time

The number of species on the planet, or in any geographical area, is the result of an equilibrium of two evolutionary processes that are ongoing: speciation and extinction. When speciation rates begin to outstrip extinction rates, the number of species will increase. Likewise, the reverse is true when extinction rates begin to overtake speciation rates. Throughout the history of life on Earth, as reflected in the fossil record, these two processes have fluctuated to a greater or lesser extent, sometimes leading to dramatic changes in the number of species on the planet as reflected in the fossil record (Figure 1).

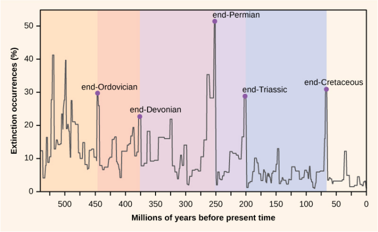


Figure 1. Extinction intensity as reflected in the fossil record has fluctuated throughout Earth's history. Sudden and dramatic losses of biodiversity, called mass extinctions, have occurred five times.

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

Peninsula and the subsequent energy release and global climate changes caused by dust ejected into the atmosphere.

Recent and Current Extinction Rates

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

One of the earlier and popularly known examples is the dodo bird. The dodo bird lived in the forests of Mauritius, an island in the Indian Ocean. The dodo bird became extinct around 1662. It was hunted for its meat by sailors and was easy prey because the dodo, which did not evolve with humans, would approach people without fear. Introduced pigs, rats, and dogs brought to the island by European ships also killed dodo young and eggs (Figure 2).

Figure 2. The dodo bird was hunted to extinction around 1662. (credit: Ed Uthman, taken in Natural History Museum, London, England)

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

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

Estimates of Present-day Extinction Rates

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

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

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

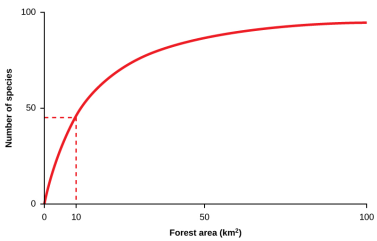


Figure 3. A typical species-area curve shows the cumulative number of species found as more and more area is sampled. The curve has also been interpreted to show the effect on species numbers of destroying habitat; a reduction in habitat of 90 percent from 100 km2 to 10 km2 reduces the number of species supported by about 50 percent.

A second approach to estimating present-time extinction rates is to correlate species loss with habitat loss, and it is based on measuring forest-area loss and understanding species–area relationships. The species-area relationship is the rate at which new species are seen when the area surveyed is increased (Figure 3). Likewise, if the habitat area is reduced, the number of species seen will also decline. This kind of relationship is also seen in the relationship between an island's area and the number of species present on the island: as one increases, so does the other, though not in a straight line. Estimates of extinction rates based on habitat loss and species–area relationships have suggested that with about 90 percent of habitat loss an expected 50 percent of species would become extinct. Figure 3 shows that reducing forest area from 100 km^2 to 10 km^2, a decline of 90 percent, reduces the number of species by about

50 percent. Species–area estimates have led to estimates of present-day species extinction rates of about 1000 E/MSY and higher.

Conservation of Biodiversity

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

Changing Human Behavior

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

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

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

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

Conservation in Preserves

Figure 4. National parks, such as Grand Teton National Park in Wyoming, help conserve biodiversity. (credit: Don DeBold)

Establishment of wildlife and ecosystem preserves is one of the key tools in conservation efforts (Figure 4). A **preserve** is an area of land set aside with varying degrees of protection for the organisms that exist within the boundaries of the preserve. In 2003, the IUCN World Parks Congress estimated that 11.5 percent of Earth's land surface was covered by preserves of various kinds. This area is large but only represents 9 out of 14 recognized major biomes and research has shown that 12 percent of all species live outside preserves.

A **biodiversity hotspot** is a conservation concept developed by Norman Myers in 1988. Hotspots are geographical areas that contain high numbers of endemic species. The purpose of the concept was to identify important locations on the planet for conservation efforts, a kind of conservation triage. By protecting hotspots, governments are able to protect a larger number of species. The original criteria for a hotspot included the presence of 1500 or more species of endemic plants and 70 percent of the area disturbed by human activity. There are now 34 biodiversity hotspots (Figure 5) that contain large numbers of endemic species, which include half of Earth's endemic plants.

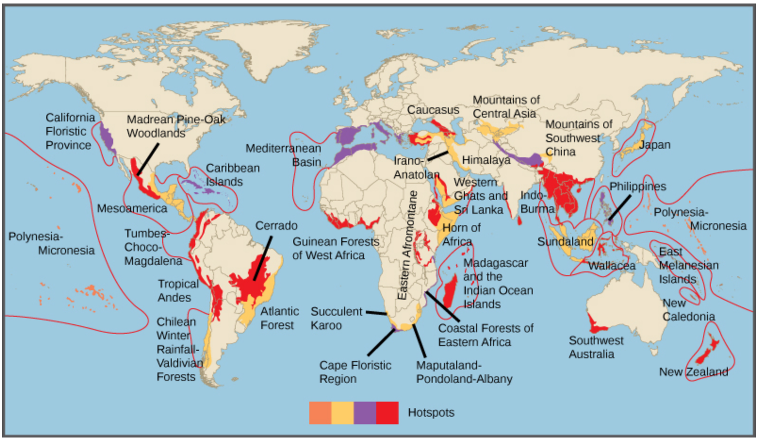


Figure 5. Conservation International has identified 34 biodiversity hotspots. Although these cover only 2.3 percent of the Earth's surface, 42 percent of the terrestrial vertebrate species and 50 percent of the world's plants are endemic to those hotspots.

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

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

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

Finally, an argument can be made that conservation preserves reinforce the cultural perception that humans are separate from nature, can exist outside of it, and can only operate in ways that do damage to biodiversity. Creating preserves reduces the pressure on human activities outside the preserves to be sustainable and non-damaging to biodiversity.

Ultimately, the political, economic, and human demographic pressures will degrade and reduce the size of conservation preserves if the activities outside them are not altered to be less damaging to biodiversity.

Habitat Restoration

Habitat restoration is the process of bringing an area back to its natural state, before it was impacted through destructive human activities. It holds considerable promise as a mechanism for maintaining or restoring biodiversity. Reintroducing wolves, a top predator, to Yellowstone National Park in 1995 led to dramatic changes in the ecosystem that increased biodiversity. The wolves (Figure 6) function to suppress elk and coyote populations and provide more abundant resources to the detritivores. Reducing elk populations has allowed revegetation of riparian (the areas along the banks of a stream or river) areas, which has increased the diversity of species in that habitat. Reduction of coyote populations by wolves has increased the prey species previously suppressed by coyotes. In this habitat, the wolf is a **keystone species**, meaning a species that is instrumental in maintaining diversity within an ecosystem. Removing a keystone species from an ecological community causes a collapse in diversity. The results from the Yellowstone experiment suggest that restoring a keystone species effectively can have the effect of restoring biodiversity in the community. Ecologists have argued for the identification of keystone species where possible and for focusing protection efforts on these species. It makes sense to return the keystone species to the ecosystems where they have been removed.

Other large-scale restoration experiments underway involve dam removal. In the United States, since the mid-1980s, many aging dams are being considered for removal rather than replacement because of shifting beliefs about the ecological value of free-flowing rivers. The measured benefits of dam removal include restoration of naturally fluctuating water levels (often the purpose of dams is to reduce variation in river flows), which leads to increased fish diversity and improved water quality. In the Pacific Northwest of the United States, dam removal projects are expected to increase populations of salmon, which is considered a keystone species because it transports nutrients to inland ecosystems during its annual spawning migrations. In other regions, such as the Atlantic coast, dam removal has allowed the return of other spawning anadromous fish species (species that are born in fresh water, live most of their lives in salt water, and return to fresh water to spawn). Some of the largest dam removal projects have yet to occur or have happened too recently for the consequences to be measured, such as Elwha Dam on the Olympic Peninsula of Washington State. The large-scale ecological experiments that these removal projects constitute will provide valuable data for other dam projects slated either for removal or construction.

Figure 6. This photograph shows the Gibbon wolf pack in Yellowstone National Park, March 1, 2007. Wolves have been identified as a keystone species. (credit: Doug Smith, NPS)

The Role of Zoos and Captive Breeding

Figure 7. Zoos and captive breeding programs help preserve many endangered species, such as this golden lion tamarin. (credit: Garrett Ziegler)

Zoos have sought to play a role in conservation efforts both through captive breeding programs and education (Figure 7). The transformation of the missions of zoos from collection and exhibition facilities to organizations that are dedicated to conservation is ongoing. In general, it has been recognized that, except in some specific targeted cases, captive breeding programs for endangered species are inefficient and often prone to failure when the species are reintroduced to the wild. Zoo facilities are far too limited to contemplate captive breeding programs for the numbers of species that are now at risk. Education, on the other hand, is a potential positive impact of zoos on conservation efforts, particularly given the global trend to urbanization and the consequent reduction in contacts between people and wildlife. A number of studies have been performed to look at the effectiveness of zoos on people's attitudes and actions regarding conservation and at present, the results tend to be mixed.

9. Food Resources

MATTHEW R. FISHER

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.

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.

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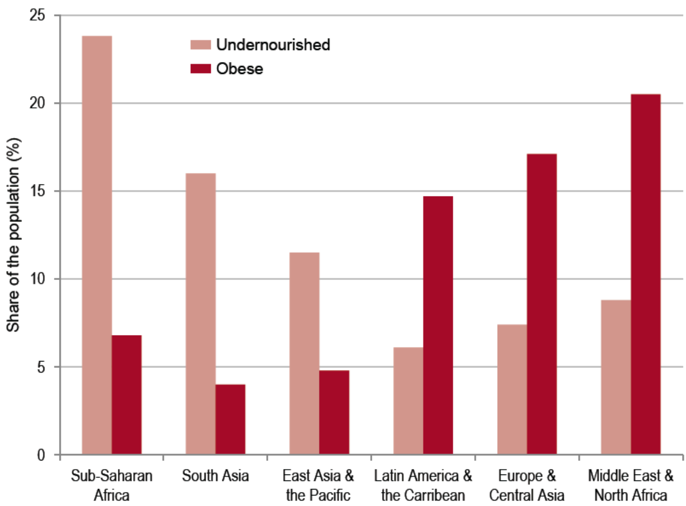
Food **stability** is when a population, household, or individual has access to food at all times and does not risk losing access as a consequence of cyclical events, such as the dry season**.** When some lacks food stability, they have **malnutrition,** a lack of essential nutrients. This is economically 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.



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.

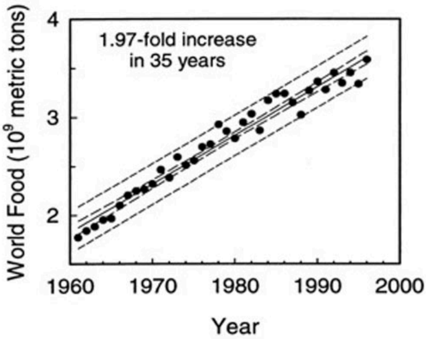
Agriculture

Agriculture is the human enterprise by which natural ecosystems are transformed into ones devoted to the production of food, fiber, and, increasingly, fuel. Given the current size of the human population, agriculture is essential. Without the enhanced production of edible biomass that characterizes agricultural systems, there would simply not be enough to eat. The land, water, and energy resources required to support this level of food production, however, are vast. Thus agriculture represents a major way in which humans impact terrestrial ecosystems.

For centuries scholars have wrestled with the question of how many people Earth can feed. In 1798 English political economist Thomas Robert Malthus published what would become one of the most famous pamphlets in social science, *An Essay on the Principle of Population*. Malthus proposed that because population tended to increase at a geometric (exponential) rate, while food supplies could only grow at an arithmetic rate, all living creatures tended to increase beyond their available resources.

"Man is necessarily confined in room," Malthus argued. "When acre has been added to acre till all fertile land is occupied, the yearly increase of food must depend upon the melioration of the land already in possession. This is a fund; which, from the nature of all soils, instead of increasing must gradually be decreasing". The resulting scarcity, he predicted, would limit human population growth through both “positive checks,” such as poverty, diseases, wars, and famines, and self-imposed “negative checks,” including late marriage and sexual abstinence.

In terms of global food production, however, Malthus has so far been proved wrong because his essay failed to take into account the ways in which agricultural productivity of cultivated lands, measured in terms of harvested (typically edible) biomass, could be enhanced. Agriculture involves the genetic modification of plant and animal species, as well as the manipulation of resource availability and species interactions. Scientific and technological advances have made agriculture increasingly productive by augmenting the resources needed to support photosynthesis and by developing plants and animals with enhanced capacity to convert such resources into a harvestable form. The outcome is that world food production has in fact kept up with rapid population growth. Gains have been especially dramatic in the past 50 years.



World food production, 1961–1996 (measured as the sum of cereals, coarse grains, and root crops) © David Tilman. World food production grew at unprecedented rates in the second half of the 20th century, increasing available food supplies in most regions except for sub-Saharan Africa.

But these gains carry with them serious environmental costs. Large-scale agriculture has reduced biodiversity, fragmented natural ecosystems, diverted or polluted freshwater resources, and altered the nutrient balance of adjacent and downstream ecosystems. Agriculture also consumes major amounts of energy and generates greenhouse gas emissions that contribute to global climate change. However, these negative impacts must be weighed against human demand for food, as well as the fact that agriculture is the primary livelihood for 40 percent of the human population. In some countries, more than 80 percent of the population makes a livelihood from farming, so increasing agricultural productivity not only makes more food available but also increases incomes and living standards.

The future impacts of agriculture will depend on many factors, including world demand for food, the availability and cost of resources needed to support high levels of productivity, and technological advances to make agriculture more efficient. Global climate change is expected to alter temperature, precipitation, and weather patterns worldwide, thus changing many fundamental conditions that guide current agricultural practice.

Conventional Agriculture

As agriculture became increasingly dependent on technological inputs throughout the 20th century, it also underwent a structural shift, particularly in developed countries. Instead of raising a diverse mix of crops, farmers increasingly planted large holdings of one or a few crop varieties that had been developed for high yields. Monoculture makes it easier to cultivate large acreages more efficiently, especially using mechanized equipment and chemical inputs. However, these artificial ecosystems are vulnerable to outbreaks of pests and pathogens because they do not have natural protection from genetic diversity and they are typically nutrient-rich, thanks to abundant fertilizer use. Moreover, many pest species have adapted to spread rapidly in ecosystems where recent disturbances, such as plowing, have eliminated natural predators.

Agricultural pests include insects, mammals such as mice and rats, unwanted plants (weeds), fungi, and microorganisms such as bacteria and viruses. Humans have controlled pests with naturally-occurring substances such as salt, sulfur, and arsenic for centuries, but synthetic pesticides, first developed during World War II, are generally more effective.

Many of the first pesticides that were widely used for agriculture were organochlorines such as DDT (dichloro diphenyl trichloroethane), aldrin, dieldrin, and heptachlor. These substances are effective against a range of insects and household pests, but in the 1950s and 1960s they were shown to cause human health effects including dizziness, seizures, respiratory illness, and immune system dysfunction. Most organochlorines have been banned in the United States and other developed countries but remain in use in developing countries.

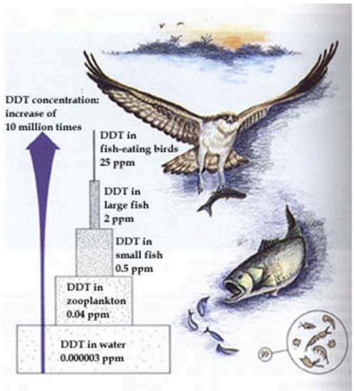
In her 1962 book *Silent Spring*, biologist and author Rachel Carson drew wide-scale public attention to the environmental effects of pesticides. Carson described how actions such as spraying elm trees with broad-spectrum pesticides to prevent Dutch elm disease severely affected many other parts of local ecosystems (Box 1).

Box 1

The trees are sprayed in the spring (usually at the rate of 2 to 5 pounds of DDT per 50-foot tree, which may be the equivalent of as much as *23 pounds per acre* where elms are numerous) and often again in July, at about half this concentration. Powerful sprayers direct a stream of poison to all parts of the tallest trees, killing directly not only the target organism, the bark beetle, but other insects, including pollinating species and predatory spiders and beetles. The poison forms a tenacious film over the leaves and bark. Rains do not wash it away. In the autumn the leaves fall to the ground, accumulate in sodden layers, and begin the slow process of becoming one with the soil. In this they

> are aided by the toil of the earthworms, who feed in the leaf litter, for elm leaves are among their favorite foods. In feeding on the leaves the worms also swallow the insecticide, accumulating and concentrating it in their bodies . . . . Undoubtedly some of the earthworms themselves succumb, but others survive to become ‘biological magnifiers’ of the poison. In the spring the robins return to provide another link in the cycle. As few as 11 large earthworms can transfer a lethal dose of DDT to a robin. And 11 worms form a small part of a day’s rations to a bird that eats 10 to 12 earthworms in as many minutes.
>
> Rachel Carson, *Silent Spring* (New York: Houghton Mifflin, 1962), pp. 107–108 (emphasis in original).

Bioaccumulation of DDT and other organochlorines drastically reduced populations of bald eagles and other large predatory birds that fed at the top of the food chain. The pesticides disrupted birds’ reproductive systems and caused them to lay eggs with very thin shells that broke before young birds hatched.



DDT accumulation in the food chain © United States Fish and Wildlife Service. Use of DDT was banned in the United States in 1972 because of its persistence, its tendency to bioaccumulate, and its adverse impacts on reproduction, especially in birds.

Organochlorines were replaced in the 1970s with other pesticides that were less toxic and more narrowly targeted to specific pests. However, many of these newer options still killed off pests' natural enemies, and when the insecticides were used repeatedly over time, pests became resistant to them through natural selection (many types of insects can develop through entire generations in days or weeks). Today hundreds of species of insects and weeds are resistant to major pesticides and herbicides.

In response some farmers have turned to methods such as releasing natural insect predators or breeding resistance into crops. For example, U.S. farmers can buy corn seeds that have been engineered to resist rootworms, corn borers, or both pests, depending on which are present locally, as well as corn that has been developed to tolerate herbicides. Others practice integrated pest management (IPM), an approach under which farmers consider each crop and pest problem as a whole and design a targeted program drawing on multiple control technologies, including pesticides, natural predators, and other methods.

In one notable case, Indonesia launched an IPM program in 1986 to control the brown planthopper, a notorious pest that lays its eggs inside rice plant stalks, out of range of pesticides. Outreach agents trained farmers to monitor their fields for planthoppers and their natural predators, and to treat outbreaks using minimal pesticide applications or alternative methods such as biological controls. Over the following decade, rice production increased by 15 percent while pesticide use fell by 60 percent. Yields on IPM lands rose from 6 to almost 7.5 tons of rice per hectare.

Gathering insects for identification during IPM training, Indonesia © J.M. Micaud, Food and Agriculture Organization. Field schools advance IPM programs by enabling farmers to see and compare the results of various pest control methods.

Plowing originally developed as a way to control pests (weeds), but created new issues in the process. Bare lands that have been plowed but have not yet developed crop cover are highly susceptible to erosion. The Dust Bowl that occurred in the United States in the 1930s was caused partly by poor agricultural practices. With support from the federal government, farmers plowed land that was too dry for farming across the Great Plains, destroying prairie grasses that held topsoil in place. When repeated droughts and windstorms struck the central and western states, hundreds of millions of tons of topsoil blew away. Today a similar process is taking place in northern China, where over-plowing and overgrazing are expanding the Gobi Desert and generating huge dust storms that scour Beijing and other large cities to the east.

Excessive plowing can also depress crop production by altering soil microbial communities and contributing to the breakdown of organic matter. To conserve soil carbon and reduce erosion, some farmers have turned to alternative practices such as no-till or direct-drill agriculture, in which crops are sown without cultivating the soil in advance. Direct drilling has been widely adopted in Australia, and some 17.5 percent of U.S. croplands were planted using no-till techniques as of the year 2000 (*footnote 8*).

No-till agriculture enhances soil development and fertility. It is usually practiced in combination with methods that leave crop residues on the field, which helps to preserve moisture, prevent erosion, and increase soil carbon pools. However, no-till requires an alternative strategy for weed control and thus frequently involves substantial use of herbicides and chemical means to control other pests.

Many subsistence farmers in traditional societies raise livestock along with their crops, either for their families' use or for sale. But in industrialized nations, animal agriculture has been transformed in much the same way as crop production over the past century. Modern livestock farms are large and specialized and rely heavily on technology inputs. Like major plant crops, meat and dairy products are increasingly produced through a kind of monoculture in which farmers raise one or a few animal strains that have been bred to maximize output—hens that lay more eggs, dairy cows that produce more milk, or pigs that grow quickly and develop lean meat. Producers use technological inputs, such as antibiotics and hormone treatments, to make animals grow larger and more quickly.

To maximize efficiency, large-scale livestock farms confine animals indoors instead of letting them range outside (Fig. 10). Confining animals makes it easier to control the amount and type of feed they receive, administer medications and growth supplements, and artificially inseminate breeding females. But it also generates new management issues. Crowding stresses animals and promotes disease transmission, so many livestock farmers use antibiotics not only to treat sick animals but to prevent illnesses and promote growth. Many of these drugs are identical or similar to antibiotics used in human medicine, so their overuse threatens human health by promoting the development of drug-resistant bacterial strains that can infect humans through the food chain or via direct exposure to farm animals or wastes.

In addition, large farms accumulate massive quantities of animal waste. One cow can produce more than 40 pounds of manure per day. Manure liquefies when it is washed out of barns, so it is too heavy to transport economically over long distances. Many large farms store millions of gallons of manure onsite in tanks or lagoons (which may be lined or unlined, depending on local regulations), until it can be used on neighboring fields.

Confined hog production facility © United States Geological Survey, Toxic Substances Hydrology Program. Large hog farms may house 10,000 or more hogs indoors for their entire life spans. On many U.S. farms, breeding sows are kept for weeks at a time in individual crates too narrow for the animals to turn around.

When manure leaks or spills from storage, it sends large pulses of nutrients into local water bodies, causing algal blooms that deplete dissolved oxygen in the water and kill fish when they die and decompose. Nutrient pollution also occurs when manure is applied too heavily to farmland, so that plants cannot take up all of the available nitrogen and phosphate before the manure leaches into nearby rivers and streams. Excess nutrients, mainly from agricultural runoff, are a major cause of "dead zones" in large water bodies such as the

Chesapeake Bay and the Gulf of Mexico. Manure also pollutes water with bacteria, hormones, and other chemical residues from animal feed.

Large livestock farms also generate air pollution from manure, dust, and greenhouse gases produced in the digestive systems of cattle and sheep. Many people who live near animal feeding operations complain about smells and suffer physical symptoms such as burning eyes, sore throats, and nausea. A 2003 National Research Council study found that livestock farms produce many air pollutants that are significant hazards at scales ranging from local to global (Table 1). However, the report concluded that more analysis was required to develop accurate measurements of these emissions as a basis for regulations and that the United States lacked standards for quantifying odor, which could be caused by various combinations of hundreds of compounds.

Table 1. Potential importance of air emissions from animal feeding operations at different spatial scales. Source: Adapted from National Research Council, *Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs* (Washington, DC: National Academies Press, 2003), p. 6.

Emission	Global, national, and regional importance	Local Importance (property line or nearest dwelling)	Primary effects of concern
Ammonia (NH_3)	Major	Minor	Acid rain, haze
Nitrous oxide (N_2O)	Significant	Insignificant	Global climate change
Nitrogen oxides (NO_X)	Significant	Minor	Haze, acid rain, smog
Methane (CH_4)	Significant	Insignificant	Global climate change
Volatile organic compounds (VOCs)	Insignificant	Minor	Quality of human life
Hydrogen sulfide (H_2S)	Insignificant	Significant	Quality of human life
Particulate matter (PM10)	Insignificant	Significant	Haze
Fine particulate matter (PM2.5)	Insignificant	Significant	Health, haze
Odor	Insignificant	Major	Quality of human life

World demand for meat and dairy products is increasing, driven by population growth and rising incomes in developing countries. Because of this growth and the trend toward raising animals on large-scale farms, the FAO calls livestock farming "one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global." According to FAO's estimates, livestock production generates 18 percent of world greenhouse gas emissions (more than the transport sector), accounts for 8 percent of world water use, and is probably the largest sectoral water pollution source.

With global meat and dairy production predicted to roughly double between 2000 and 2050, these environmental impacts will have to be drastically reduced just to keep agricultural pollution from worsening.

Agriculture and Genetic Technology

Farmers have manipulated the genetic makeup of plants and animals since the dawn of agriculture. Initially they used selective breeding to promote qualities that made breeds readily usable for agriculture, such as animals that domesticated well and plants that were easy to harvest. Next, breeders focused on varieties that could be grown outside of their native geographic range—for example, overcoming natural photoperiod requirements (the amount of daylight that plants need to flower). In the twentieth century, plant geneticists selected for traits that would allow plants to use high levels of water and nitrogen to increase yields. Similarly, animal breeders worked to increase the amount of meat or milk that various domestic animal lines produced.

Today classical agricultural breeding is a highly quantitative science that uses genetic markers (specific DNA sequences) to select for desired characteristics. This approach enables scientists to manipulate the genetic makeup of crops with substantial precision, as long as genetic variation exists for particular traits. Agricultural breeders also use biotechnology to move genes across taxonomic barriers, combining genetic material from species that would not cross-breed naturally. For example, Bt corn has been modified by inserting a gene from the bacterium *Bacillus thuringiensis* that kills harmful insects so that farmers do not need to use insecticide.

Since the mid-1990s, the U.S. Department of Agriculture has approved 63 genetically engineered (GE) crops for unrestricted sale, including strains of corn, soybeans, cotton, potatoes, wheat, canola, and papaya. Most of these crops have been developed to tolerate herbicides or resist insects or fungi, while others have been engineered for specific product qualities such as longer shelf life. Products under development include grains, field crops, fruits, vegetables, trees, and flowers designed to achieve desirable growing properties such as cold or drought resistance or efficient use of nitrogen. The extent to which such strategies will be able to enhance agricultural productivity, however, remains to be seen.

An alternative use of biotechnology that some supporters advocate is to develop crops with improved nutritional content to combat nutritional disorders. One widely-publicized product is golden rice, a rice variety into which several "trans" or foreign genes have been added so that the plant produces beta-carotene (vitamin A) in its grains. Vitamin A deficiencies are widespread in societies that consume rice-based diets, causing thousands of cases of blindness and premature deaths among children in developing countries every year. Researchers are currently working to produce golden rice that contains the recommended daily allowance of vitamin A in a 100 to 200 gram serving, as well as to ensure the bioavailability of the beta-carotene contained within the modified rice grains. But not everyone is convinced by this approach: some experts argue that the same goals could be met more cheaply by promoting balanced, diverse diets in the target countries.

Conventional and golden rice © 2007. Golden Rice Humanitarian Board. Along with wheat, maize (corn), and potatoes, rice is one of the world's most important staple foods. These foods contain widely varying levels of many important micronutrients. Golden rice is designed to eliminate one deficiency by producing vitamin A in its grains.

In addition to questioning whether agricultural and nutritional goals might be more effectively met using more traditional approaches, critics have raised many concerns about GE foods, including potential harm to nearby ecosystems and the possibility that GE crops or animals will hybridize with and alter the genetic makeup of wild species. For example, over-planting Bt-resistant crops could promote increased Bt resistance among pests, while genes from GE crops could give wild plants qualities that make them more weedy and invasive. Although most of these effects will probably be benign, it is hard to predict when and where GE species could have harmful effects on surrounding ecosystems.

A 2002 National Research Council report concluded that genetically modified plants posed the same broad types of environmental risks as conventionally-produced hybrids, like the strains introduced during the Green Revolution. For example, both kinds of plants could spread into surrounding ecosystems and compete with local species. But the report noted that either type of plant could have specific traits that posed unique threats and accordingly called for case-by-case regulation of new GE strains. The committee also observed that future generations of GE plants are likely to have multiple introduced traits and forecast that these products will raise issues that cannot be predicted based on experience with early herbicide- and pest-resistant crops.

Sustainable Agriculture

Growing concern about agricultural intensification in developed countries and its negative environmental impacts spurred an alternative movement in the 1970s to promote what advocates called sustainable agriculture. This perspective drew inspiration from sources that included organic farming (raising crops and animals with minimal synthetic inputs), the international environmental movement, and development advocates who criticized the Green Revolution for relying too heavily on pesticides and fertilizer. Ecology is a central pillar of sustainable agriculture, which treats farmed areas first and foremost as ecosystems, albeit unique ecosystems that have been disturbed and simplified by harvesting.

Few people would argue against the concept of sustainable agriculture, but there is no universally-agreed definition of what it means. Agricultural economist Gordon Conway describes sustainability as "the ability of an agroecosystem [an agricultural ecosystem and its social and economic setting] to maintain productivity in the face of stress or shock." Farmers use countermeasures to respond to stresses and shocks. They may draw on resources that are internal to the system, such as plants' natural pest resistance, or on outside inputs like herbicides and fertilizers.

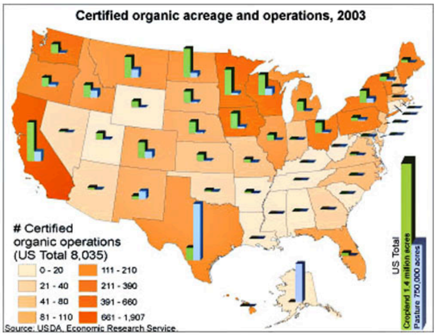
Internal inputs typically rely on natural resources. Figure 15 shows the re-emerging practice of green manuring—tilling fresh plant material into soil to improve its physical and biological qualities. Outside inputs may be equally useful, but they usually cost more and may alter farming systems in unexpected ways—for example, introducing new species that compete with established crops.

Chopping and disking mustard green manure, Washington state, 2003 © Washington State University Extension. Farmers have practiced green manuring for centuries, but the technique has become more sophisticated with growing understanding of soil ecology, plant biochemistry, and nutrient cycling.

Other formulations of sustainable agriculture, including legislation passed by the U.S. Congress in 1990, present it as a compromise between several sets of social goals, including but not limited to environmental conservation. Producing enough food, fuel, and fiber to meet human needs is a major objective, along with improving environmental quality, using non-renewable resources efficiently, and ensuring that farmers can earn reasonable livings from their products (*footnote 17*). In terms of methods, sustainable agriculture typically stresses treating soil as an ecosystem and using methods to keep it healthy, such as retaining organic matter and preserving diverse communities of soil organisms.

Many people equate sustainable agriculture with organic farming, which is practiced according to national legal standards in more than 60 countries, including the United States, the European Union, Britain, Canada, and Australia. Generally, organic standards bar the use of synthetic pesticides, herbicides, fertilizers, and genetically modified organisms for crop production and use of antibiotics, hormones, and synthetic feeds for animals. Organic agriculture typically has less severe environmental impacts than intensive farming with synthetic inputs. On average, organic farming conserves biodiversity, improves the structure and organic content of soil, leaches less nitrate into water bodies, and produces much less pesticide pollution.

As of 2002–2003, about 4 percent of utilized agricultural land in the European Union and up to 4 percent of farmed land for certain crops in the United States was farmed organically. Together, the United States and the E.U. account for 95 percent of global organic food sales.



U.S. certified organic acreage and operations, 2003 © United States Department of Agriculture, Economic Research Service. Organic farming accounts for a small fraction of land under cultivation worldwide, but interest in organic methods is rising. Organically grown products typically earn significant market premiums over conventional crops.

Organic farming is not without its drawbacks. Output from organic farms is typically lower than from conventional agriculture for at least several years after shifting to organic production, because it takes time to restore soil productivity naturally and establish beneficial insect populations. Organic agriculture is more labor-intensive than conventional farming, so production costs are higher and farmers must receive higher prices to make a profit. And transitioning to organic production takes several years, so it is too expensive and difficult for small-scale farmers without access to technical assistance and transition funding.

With world population projected to rise from 6.5 billion in 2006 to roughly 10 billion by 2050, and growing demand for meat in developing countries (which increases demand for grain as livestock feed), world grain production may have to double in coming decades. If nations take the intensive route to this goal, using even more fertilizer, pesticides, and irrigation, nutrient pollution and freshwater depletion will increase well beyond current levels—the antithesis of sustainable agriculture (*footnote 18*).

One potential solution currently at the experimental stage is “precision agriculture”—using remote sensing to help farmers target fertilizer, herbicides, seeds, and water to exact locations on a field, so that resources are not over-applied or used where they are not needed. For example, satellite data could identify sectors within large cultivated fields that needed additional water or fertilizer and communicate the information to farmers driving machinery equipped with global positioning system receivers (reducing the need to apply inputs uniformly across entire fields).

More broadly, agriculture will have to become more efficient in order to double world grain production without further degrading the environment. No single innovation will provide a complete solution. Rather, feeding the world sustainably is likely to require a combination of many technological inputs and sustainable techniques.

10. Energy Resources

JEAN BRAINARD

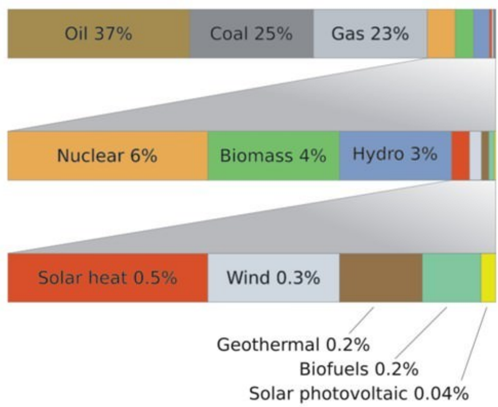
Non-Renewable Energy

Sufficient, reliable sources of energy are a necessity for industrialized nations. Energy is used for heating, cooking, transportation and manufacturing. Energy can be generally classified as non-renewable and renewable. Over 85% of the energy used in the world is from non-renewable supplies. Most developed nations are dependent on **non-renewable** energy sources such as fossil fuels (coal and oil) and nuclear power. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Some sources of energy are renewable or potentially renewable. Examples of renewable energy sources are: solar, geothermal, hydroelectric, biomass, and wind. Renewable energy sources are more commonly by used in developing nations.

A non-renewable resource is not regenerated or restored on a time scale comparative to its consumption. Non-renewable resources exist in fixed amounts (at least relative to our time frame), and can be used up. The classic examples are fossil fuels such as petroleum, coal, and natural gas. Fossil fuels have formed from remains of plants (for coal) and phyto- and zoo-plankton (for oil) over periods from 50 to 350 million years. Ecologist Jeff Dukes estimates that 20 metric tons of phytoplankton produce 1 liter of gasoline! We have been consuming fossil fuels for less than 200 years, yet even the most optimistic estimates suggest that remaining reserves can supply our needs for

Coal: 252 years.
Gas: 72 years
Oil: 45 years

Nuclear power is considered a non-renewable resource because uranium fuel supplies are finite. Some estimates suggest that known economically feasible supplies could last 70 years at current rates of use – although known, and probably unknown reserves are much larger, and new technologies could make some reserves more useful.



Global energy use includes mostly non-renewable (oil, coal, gas, and nuclear) but increasing amounts of renewable (biomass, hydro, solar, wind, geothermal, biofuels, and solar photovoltaic) resources.

Today 80% of the world's energy comes from fossil fuels.Fossil fuels are formed hundreds of millions of years ago from decomposition of the bodies of living things became buried. See a description of this process this site: http://www.fossil.energy.gov/education/energylessons/coal/gen_howformed.html

The reasons why fossil fuels are so widely used today:

1. Fossil fuel is easy to store and transport

2. Society's energy infrastructure and technology for transportation is geared for using fossil fuel energy
3. Fossil fuels like coal and oil are easy to store and transport, while natural gas is used in countries that have natural gas pipeline networks.

Society's dependence on fossil fuel is problematic because:

1. Fossil fuel supply are finite and crude oil supplies are running low
2. Most crude oil producing countries are developing and politically unstable, so that crude oil can suddenly be in short supply due to politics

    - E.g. OPEC's (Organization of Petroleum Exporting Countries) 1973-74 oil embargo against the US for supporting Israel in the Arab-Israel war caused widespread panic, skyrocketing prices, and spurred inflation.

3. Burning fossil fuels creates air pollution and causes acid rain
4. Burning fossil fuels released carbon dioxide into the atmosphere and contributes to global climate change.

COAL

Coal is the most abundant fossil fuel in the world with an estimated reserve of one trillion metric tons. Most of the world's coal reserves exist in Eastern Europe and Asia, but the United States also has considerable reserves. Coal formed slowly over millions of years from the buried remains of ancient swamp plants. During the formation of coal, carbonaceous matter was first compressed into a spongy material called "peat," which is about 90% water. As the peat became more deeply buried, the increased pressure and temperature turned it into coal.

Different types of coal resulted from differences in the pressure and temperature that prevailed during formation. The softest coal (about 50% carbon), which also has the lowest energy output, is called **lignite**. Lignite has the highest water content (about 50%) and relatively low amounts of smog-causing sulfur.

With increasing temperature and pressure, lignite is transformed into bituminous coal (about 85% carbon and 3% water). **Anthracite** (almost 100% carbon) is the hardest coal and also produces the greatest energy when burned. Less than 1% of the coal found in the United States is anthracite. Most of the coal found in the United States is **bituminous**. Unfortunately, bituminous coal has the highest sulfur content of all the coal types. When the coal is burned, the pollutant sulfur dioxide is released into the atmosphere.

Coal mining creates several environmental problems. Coal is most cheaply mined from near-surface deposits using strip mining techniques. **Strip-mining** causes considerable environmental damage in the forms of erosion and habitat destruction. **Sub-surface mining** of coal is less damaging to the surface environment, but is much more hazardous for the miners due to tunnel collapses and gas explosions. Extraction of coal from underground mines is dangerous to miners and environmentally devastating to natural habitats for surface mining (i.e. coal scraped off the surface of the ground).

Currently, the world is consuming coal at a rate of about 5 billion metric tons per year. The main use of coal is for power generation, because it is a relatively inexpensive way to produce power.

Coal is used to produce over 50% of the electricity in the United States. In addition to electricity production, coal is sometimes used for heating and cooking in less developed countries and in rural areas of developed countries. If consumption continues at the same rate, the current reserves will last for more than 200 years. The burning of coal results in significant atmospheric pollution. The sulfur contained in coal forms sulfur dioxide when burned. Harmful nitrogen oxides, heavy metals, and carbon dioxide are also released into the air during coal burning. The harmful emissions can be reduced by installing scrubbers and electrostatic precipitators in the smokestacks of power plants. The toxic ash remaining after coal burning is also an environmental concern and is usually disposed into landfills.

Coal is the world's most abundant fossil fuel. Table 4 – Top 10 poducers of coal in 2008

Rank	Country	Coal Produced in Metric Tonnes
1	China	2761
2	USA	1007
3	India	490
4	Australia	325
5	Russia	247
6	Indonesia	246
7	South Africa	236
8	Kazakhstan	104
9	Poland	84
10	Colombia	79

Table data from: http://www.worldcoal.org/resources/coal-statistics/ (you do not need to go to this site)Table 5 – Top 11 consumers of coal in 2007

Rank	Country	Coal Produced in Metric Tonnes
1	South Africa	94%
2	Poland	93%
3	PR China	81%
4	Australia	76%
5	Israel	71%
6	Kazakhstan	70%
7	India	68%
8	Czech Rep	62%
9	Morocco	57%
10	Greece	55%
11	USA	49%

Table data from: http://www.worldcoal.org/resources/coal-statistics/ (you do not need to go to this site)

OIL

Crude oil or liquid petroleum, is a fossil fuel that is refined into many different energy products (e.g., gasoline, diesel fuel, jet fuel, heating oil). Oil forms underground in rock such as **shale**, which is rich in organic materials. After the oil forms, it migrates upward into porous reservoir rock such as sandstone or limestone, where it can become trapped by an overlying impermeable cap rock. Wells are drilled into these oil reservoirs to remove the gas and oil. Over 70 percent of oil fields are found near tectonic plate boundaries, because the conditions there are conducive to oil formation.

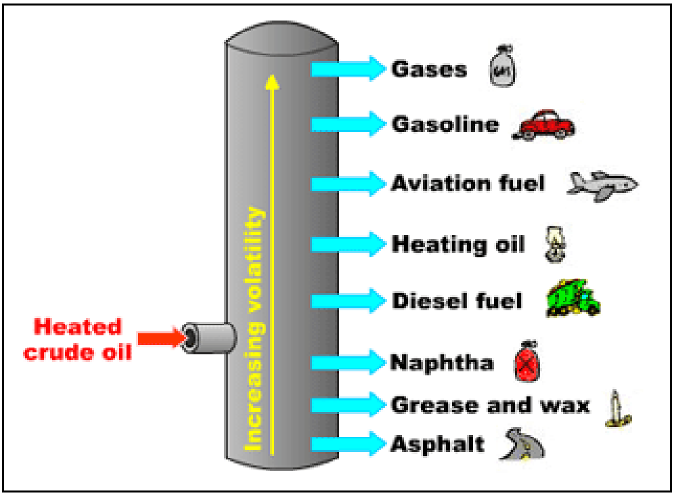
Oil recovery can involve more than one stage. The primary stage involves pumping oil from reservoirs under the normal reservoir pressure. About 25 percent of the oil in a reservoir can be removed during this stage. The secondary recovery stage involves injecting hot water into the reservoir around the well. This water forces the remaining oil toward the area of the well from which it can be recovered.

PHOTO CREDIT: VAHE PEROOMIAN

CHEVRON OIL REFINERY IN EL SEGUNDO, CALIFORNIA

Sometimes a tertiary method of recovery is used in order to remove as much oil as possible. This involves pumping steam, carbon dioxide gas or nitrogen gas into the reservoir to force the remaining oil toward the well. Tertiary recovery is very expensive and can cost up to half of the value of oil removed. Carbon dioxide used in this method remains sequestered in the deep reservoir, thus mitigating its potential greenhouse effect on the atmosphere. The refining process required to convert crude oil into useable hydrocarbon compounds involves boiling the crude and separating the gases in a process known as fractional distillation. Besides its use as a source of energy, oil also provides base material for plastics, provides asphalt for roads and is a source of industrial chemicals.

Over 50 percent of the world's oil is found in the Middle East; sizeable additional reserves occur in North America. Most known oil reserves are already being exploited, and oil is being used at a rate that exceeds the rate of discovery of new sources.



REFINERY COMPONENTS OF CRUDE OIL

If the consumption rate continues to increase and no significant new sources are found, oil supplies may be exhausted in another 30 years or so.

Despite its limited supply, oil is a relatively inexpensive fuel source. It is a preferred fuel source over coal. An equivalent amount of oil produces more kilowatts of energy than coal. It also burns cleaner, producing about 50 percent less sulfur dioxide.

Oil, however, does cause environmental problems. The burning of oil releases atmospheric pollutants such as sulfur dioxide, nitrogen oxides, carbon dioxide and carbon monoxide. These gases are smog-precursors that pollute the air and greenhouse gases that contribute to global warming. Another environmental issue associated with the use of oil is the impact of oil drilling. Substantial oil reserves lie under the ocean. Oil spill accidents involving drilling platforms kill marine organisms and birds.

Some reserves such as those in northern Alaska occur in wilderness areas. The building of roads, structures and pipelines to support oil recovery operations can severely impact the wildlife in those natural areas.

 See this animation about how oil recovery works: click here.

Crude oil is used to produce gasoline and many other petroleum products. See the list in this site http://www.ranken-energy.com/Products%20from%20Petroleum.htmTable 2 – Top 10 producers of crude oil in 2008 (thousands of barrels per day)

Rank	Country	Production
1	Saudi Arabia	10,782
2	Russia	9,790
3	United States	8,514
4	Iran	4,174
5	China	3,973
6	Canada	3,350
7	Mexico	3,186
8	United Arab Emirates	3,046
9	Kuwait	2,741
10	Venezuela	2,643

Table data from: http://tonto.eia.doe.gov/country/index.cfm (you do not need to go to this site)Table 3 – Top 10 consumers of crude oil in 2008 (thousands of barrels per day)

Rank	Country	Consumption
1	United States	19,498
2	China	7,831
3	Japan	4,785
4	India	2,962
5	Russia	2,916
6	Germany	2,569
7	Brazil	2,485
8	Saudi Arabia	2,376
9	Canada	2,261
10	Korea, South	2,175

Table data from: http://tonto.eia.doe.gov/country/index.cfm (you do not need to go to this site)

NATURAL GAS

Natural gas consists of primarily methane and it can be formed in 2 ways:

- Biogenic gas – created at shallow depths by bacterial anaerobic decomposition of organic matter or "Swamp gas"
- Thermogenic gas or fossil natural gas – results from compression and heat deep underground, found above coal or crude oil
    - This means that countries with large reserve of coal or crude oil also have large reserves of natural gas. Natural gas is harder to transport than crude oil or coal. Many developing countries that do not have natural gas networks pipeline or infrastructure to liquefy the gas waste this energy resource.The gas is

often burned off at the crude oil or coal extraction site (called flaring) rather than used for supplying energy needs.

◦ Picture from: http://www.flickr.com/photos/doneastwest/2368728311/

Natural gas production is often a by-product of oil recovery, as the two commonly share underground reservoirs. Natural gas is a mixture of gases, the most common being **methane** (CH_4). It also contains some **ethane** (C_2H_5),**propane** (C_3H_8), and **butane** (C_4H_{10}). Natural gas is usually not contaminated with sulfur and is therefore the cleanest burning fossil fuel. After recovery, propane and butane are removed from the natural gas and made into **liquefied petroleum gas** (LPG). LPG is shipped in special pressurized tanks as a fuel source for areas not directly served by natural gas pipelines (e.g., rural communities). The remaining natural gas is further refined to remove impurities and water vapor, and then transported in pressurized pipelines. The United States has over 300,000 miles of natural gas pipelines. Natural gas is highly flammable and is odorless. The characteristic smell associated with natural gas is actually that of minute quantities of a smelly sulfur compound (ethyl mercaptan) which is added during refining to warn consumers of gas leaks.

The use of natural gas is growing rapidly. Besides being a clean burning fuel source, natural gas is easy and inexpensive to transport once pipelines are in place. In developed countries, natural gas is used primarily for heating, cooking, and powering vehicles. It is also used in a process for making ammonia fertilizer. The current estimate of natural gas reserves is about 100 million metric tons. At current usage levels, this supply will last an estimated 100 years. Most of the world's natural gas reserves are found in Eastern Europe and the Middle East.

NATURAL GAS STATION IN GLENDALE, CALIFORNIA

OIL SHALE AND TAR SANDS

Oil shale and tar sands are the least utilized fossil fuel sources. **Oil shale**is sedimentary rock with very fine pores that contain **kerogen**, a carbon-based, waxy substance. If shale is heated to 490° C, the kerogen vaporizes and can then be condensed as shale oil, a thick viscous liquid. This shale oil is generally further refined into usable oil products. Production of shale oil requires large amounts of energy for mining and processing the shale. Indeed about a half barrel of oil is required to extract every barrel of shale oil. Oil shale is plentiful, with estimated reserves totaling 3 trillion barrels of recoverable shale oil. These reserves alone could satisfy the world's oil needs for about 100 years. Environmental problems associated with oil shale recovery include: large amounts of water needed for processing, disposal of toxic waste water, and disruption of large areas of surface lands.

Tar sand is a type of sedimentary rock that is impregnated with a very thick crude oil. This thick crude does not flow easily and thus normal oil recovery methods cannot be used to mine it. If tar sands are near the surface, they can be mined directly. In order to extract the oil from deep-seated tar sands, however, steam must be injected into the reservoir to make the oil flow better and push it toward the recovery well. The energy cost for producing a barrel of tar sand is similar to that for oil shale. The largest tar-sand deposit in the world is in Canada and contains enough material (about 500 billion barrels) to supply the world with oil for about 15 years. However, because of environmental concerns and high production costs these tar sand fields are not being fully utilized.

NUCLEAR POWER

In most electric power plants, water is heated and converted into steam, which drives a turbine-generator to produce electricity. Fossil-fueled power plants produce heat by burning coal, oil, or natural gas. In a **nuclear power plant**, the **fission of uranium atoms** in the reactor provides the heat to produce steam for generating electricity.

Several commercial reactor designs are currently in use in the United States. The most widely used design consists of a heavy steel pressure vessel surrounding a reactor core. The **reactor core** contains the uranium fuel, which is formed into cylindrical ceramic pellets and sealed in long metal tubes called **fuel rods**. Thousands of fuel rods form the reactor core. Heat is produced in a nuclear reactor when neutrons strike uranium atoms, causing them to split in a continuous chain reaction. **Control rods**, which are made of a material such as boron that absorbs neutrons, are placed among the fuel assemblies.

PHOTO CREDIT: VAHE PEROOMIAN

MEDZEMOR NUCLEAR POWER PLANT IN ARMENIA

When the neutron-absorbing control rods are pulled out of the core, more neutrons become available for fission and the chain reaction speeds up, producing more heat. When they are inserted into the core, fewer neutrons are available for fission, and the chain reaction slows or stops, reducing the heat generated. Heat is removed from the reactor core area by water flowing through it in a closed pressurized loop. The heat is transferred to a second water loop through a heat exchanger. The water also serves to slow down, or "moderate" the neutrons which is necessary for sustaining the fission reactions. The second loop is kept at a lower pressure, allowing the water to boil and create steam, which is used to power the turbine-generator and produce electricity.

Originally, nuclear energy was expected to be a clean and cheap source of energy. Nuclear fission does not produce atmospheric pollution or greenhouse gases and it proponents expected that nuclear energy would be cheaper and last longer than fossil fuels.

Unfortunately, because of construction cost overruns, poor management, and numerous regulations, nuclear power ended up being much more expensive than predicted. The nuclear accidents at Three Mile Island in Pennsylvania and the Chernobyl Nuclear Plant in the Ukraine raised concerns about the safety of nuclear power. Furthermore, the problem of safely disposing spent nuclear fuel remains unresolved. The United States has not built a new nuclear facility in over twenty years, but with continued energy crises across the country that situation may change.

 See this animation about how nuclear power works: Click here.

Renewable Energy

Renewable energy sources are often considered alternative sources because, in general, most industrialized countries do not rely on them as their main energy source. Instead, they tend to rely on non-renewable sources such as fossil fuels or nuclear power. Because the energy crisis in the United States during the 1970s, dwindling supplies of fossil fuels and hazards associated with nuclear power, usage of renewable energy sources such as solar energy, hydroelectric, wind, biomass, and geothermal has grown.

Renewable energy comes from the sun (considered an "unlimited" supply) or other sources that can theoretically be renewed at least as quickly as they are consumed. If used at a sustainable rate, these sources will be available for consumption for thousands of years or longer. Unfortunately, some potentially renewable energy sources, such as biomass and geothermal, are actually being depleted in some areas because the usage rate exceeds the renewal rate.

A resource replenished by natural processes at a rate roughly equal to the rate at which humans consume it is a **renewable resource**. Sunlight and wind, for example, are in no danger of being used in excess of their longterm availability. Hydropower is renewed by the Earth's hydrologic cycle. Water has also been considered renewable, but overpumping of groundwater is depleting aquifers, and **pollution** threatens the use of many water resources, showing that the consequences of resource use are not always simple depletion. Soils are often considered renewable, but erosion and depletion of minerals proves otherwise. Living things (forests and fish, for example) are considered renewable because they can reproduce to replace individuals lost to human consumption. This is true only up to a point, however; overexploitation can lead to extinction, and overharvesting can remove nutrients so that soil fertility does not allow forest renewal. Energy resources derived from living things, such as ethanol, plant oils, and methane, are considered renewable, although their costs to the environment are not always adequately considered. Renewable materials would include sustainably harvested wood, cork, and bamboo as well as sustainably harvested crops. Metals and other minerals are sometimes considered renewable because they are not destroyed when they are used, and can be recycled.

Although most of our energy needs today come from fossil fuels but we are now increasingly aware that we need to find alternative energy sources. The benefits of using renewable energy sources are:

1. Most energy will never run out
2. Countries are no longer so dependent on oil producing nationals for their energy needs
3. Most renewable energy sources produce little or no air pollution and little
4. Most renewable energy sources produce little or no carbon dioxide into the atmosphere and therefore is a solution to global climate change

The reasons why renewable energy sources are NOT more widely used:

1. Most of our technology and infrastructure today is geared toward using fossil fuel energy
2. Switching to renewable energy requires expensive investments in infrastructure
3. We have limited ways to transport electricity generated by renewable energy sources that are not near electric grids.

The various ways we produce electricity from renewable energy sources is based on the principle that something has to turn turbines to generate electricity. The turning force spins giant magnets suspended within coils of metal wire inside the turbine which creates electricity inside the metal coils.

SOLAR ENERGY

Solar energy is the ultimate energy source driving the earth. Though only one billionth of the energy that leaves the sun actually reaches the earth's surface, this is more than enough to meet the world's energy requirements. In fact, all other sources of energy, renewable and non-renewable, are actually stored forms of solar energy. The process of directly converting solar energy to heat or electricity is considered a renewable energy source. Solar energy represents an essentially unlimited supply of energy as the sun will long outlast human civilization on earth. The difficulties lie in harnessing the energy. Solar energy has been used for centuries to heat homes and water, and modern technology (photovoltaic cells)has provided a way to produce electricity from sunlight.

There are two basic forms of radiant solar energy use: passive and active. **Passive solar energy** systems are static, and do not require the input of energy in the form of moving parts or pumping fluids to utilize the sun's energy.

Buildings can be designed to capture and collect the sun's energy directly. Materials are selected for their special characteristics: glass allows the sun to enter the building to provide light and heat; water and stone materials have high heat capacities. They can absorb large amounts of solar energy during the day, which can then be used during the night. A southern exposure greenhouse with glass windows and a concrete floor is an example of a passive solar heating system. **Active solar energy** systems require the input of some energy to drive mechanical devices (e.g., solar panels), which collect the energy and pump fluids used to store and distribute the energy. Solar panels are generally mounted on a south or west-facing roof. A solar panel usually consists of a glass-faced, sealed, insulated box with a black matte interior finish. Inside are coils full of a heat-collecting liquid medium (usually water, sometimes augmented by antifreeze).

The sun heats the water in the coils, which is pumped to coils in a heat transfer tank containing water. The water in the tank is heated and then either stored or pumped through the building to heat rooms or supply hot water to taps in the building.

- Has a long history of use by preindustrial age human society, e.g. using the sun to dry food or clothes There are 2 ways to harness solar energy
    - Harness the sun's heat (either directly or by concentrating the heat)
    - Convert the sun's light to electricity with photovoltaic cells
- Read about the different ways to harness solar energy from this site: http://www.getsolar.com/learn_types-of-solar-power.php Biomass and Biofuels

Photovoltaic cells generate electricity from sunlight. Hundreds of cells are linked together to provide the required flow of current. The electricity can be used directly or stored in storage batteries. Because photovoltaic cells have no moving parts, they are clean, quiet, and durable. Early photovoltaic cells were extremely expensive, making the cost of solar electric panels prohibitive. The recent development of inexpensive semiconductor materials has helped greatly lower the cost to the point where solar electric panels can compete much better cost-wise with traditionally-produced electricity.

PHOTO CREDIT: VAHE PEROOMIAN

SOLAR PHOTOVOLTAIC ARRAYS

Though solar energy itself is free, large costs can be associated with the equipment. The building costs for a house heated by passive solar energy may initially be more expensive. The glass, stone materials, and excellent insulation necessary for the system to work properly tend to be more costly than conventional building materials. A long-term comparison of utility bills, though, generally reveals noticeable savings. The solar panels used in active solar energy can be expensive to purchase, install and maintain. Leaks can occur in the extensive network of pipes required, thereby causing additional expense. The biggest drawback of any solar energy system is that it requires a consistent supply of sunlight to work. Most parts of the world have less than ideal conditions for a solar-only home because of their latitude or climate. Therefore, it is usually necessary for solar houses to have conventional backup systems (e.g. a gas furnace or hot-water heater). This double-system requirement further adds to its cost.

 See these two animations on solar energy use:

1. Solar Heating System
2. Photovoltaic Cells

WIND POWER

Wind is the result of the sun's uneven heating of the atmosphere. Warm air expands and rises, and cool air contracts and sinks. This movement of the air is called wind. Wind has been used as an energy source for millennia. It has been used to pump water, to power ships, and to mill grains. Areas with constant and strong winds can be used by wind turbines to generate electricity. In the United States, the state of California has about 20,000 **wind turbines**, and produces the most wind-generated electricity. Wind energy does not produce air pollution, can be virtually limitless, and is relatively inexpensive to produce. There is an initial cost of manufacturing the wind turbine and the costs associated with upkeep and repairs, but the wind itself is free.

The major drawbacks of wind-powered generators are they require lots of open land and a fairly constant wind supply. Less than 15% of the United States is suitable for generating wind energy. Windmills are also noisy, and some people consider them aesthetically unappealing and label them as visual pollution. Migrating birds and insects can become entangled and killed by the turning blades. However, the land used for windmill farms can be simultaneously used for other purposes such as ranching, farming and recreation.

- Has a long history of use by preindustrial age human society, e.g. windmills used to grind grain in to flour
- The fastest growing source of renewable energy
- Read about wind energy from this site: http://windeis.anl.gov/guide/basics/index.cfm

Wind power is considered a renewable resource because the rate of supply far exceeds the rate of use (

HYDROELECTRIC ENERGY

Hydroelectric power is generated by using the energy of flowing water to power generating turbines for producing electricity. Most hydroelectric power is generated by dams across large-flow rivers. A dam built across river creates a reservoir behind it. The height of the water behind the dam is greater than that below the dam, representing stored potential energy. When water flows down through the penstock of the dam, driving the turbines, some of this potential energy is converted into electricity. Hydroelectric power, like other alternative sources, is clean and relatively cheap over the long term even with initial construction costs and upkeep. But because the river's normal flow rate is reduced by the dam, sediments normally carried downstream by the water are instead deposited in the reservoir. Eventually, the sediment can clog the penstocks and render the dam useless for power generation.

Large-scale dams can have a significant impact on the regional environment. When the river is initially dammed, farmlands are sometimes flooded and entire populations of people and wildlife are displaced by the rising waters behind the dam. In some cases, the reservoir can flood hundreds or thousands of square kilometers. The decreased flow downstream from the dam can also negatively impact human and wildlife populations living downstream. In addition, the dam can act as a barrier to fish that must travel upstream to spawn. Aquatic organisms are frequently caught and killed in the penstock and the out-take pipes. Because of the large surface area of the reservoir, the local climate can change due to the large amount of evaporation occurring.

- Has a long history of use by preindustrial age human society, e.g. watermills used to grind grain in to flour
- Today hydropower mostly involves building dams across major rivers and harnessing the power of the water as it flows across the dam to turn turbines that generate electricity
- The world has maximized the use of hydropower because most of the world's major rivers have dams on them
- Building of dams causes major habitat destruction due to the large area behind the dams that become flooded
- This energy is renewable only if the river continues to flow

PHOTO CREDIT: VAHE PEROOMIAN

HYDROELECTRIC GENERATOR INSIDE HOOVER DAM

See this animation on how dams generate electricity. Click here.

BIOMASS ENERGY

Biomass energy is the oldest energy source used by humans. Biomass is the organic matter that composes the tissues of plants and animals. Until the Industrial Revolution prompted a shift to fossil fuels in the mid 18th century, it was the world's dominant fuel source. Biomass can be burned for heating and cooking, and even generating electricity. The most common source of biomass energy is from the burning of wood, but energy can also be generated by burning animal manure (dung), herbaceous plant material (non-wood), peat (partially decomposed plant and animal tissues), or converted biomass such as charcoal (wood that has been partially burned to produce a coal-like substance). Biomass can also be converted into a liquid biofuel such as ethanol or methanol. Currently, about 15 percent of the world's energy comes from biomass.

Biomass is a potentially renewable energy source. Unfortunately, trees that are cut for firewood are frequently not replanted. In order to be used sustainably, one tree must be planted for every one cut down.

Biomass is most frequently used as a fuel source in developing nations, but with the decline of fossil fuel availability and the increase in fossil fuel prices, biomass is increasingly being used as a fuel source in developed nations. One example of biomass energy in developed nations is the burning of municipal solid waste. In the United States, several plants have been constructed to burn urban biomass waste and use the energy to generate electricity.

The use of biomass as a fuel source has serious environmental effects. When harvested trees are not replanted, soil erosion can occur. The loss of photosynthetic activity results in increased amounts of carbon dioxide in the atmosphere and can contribute to global warming. The burning of biomass also produces carbon dioxide and deprives the soil of nutrients it normally would have received from the decomposition of the organic matter. Burning releases particulate matter (such as ash) into the air which can cause respiratory health problems.

- Biomass: organic material that makes up living organisms
    - More than 1 billion people use wood from trees as their principal energy source.
    - In developing nations, families gather fuelwood for heating, cooking, and lighting.
    - Biomass is only renewable not overharvested.
    - Co-firing combines biomass with coal to burn and generate electricity
    - Gasification: vaporized biomass at high temperature without oxygen produce a gas mix that can be used to produce electricity, methanol and diesel fuel

- Biofuels: biomass sources are converted into fuels to power automobiles
    - Ethanol: produced as a biofuel by fermenting plant matter (e.g. carbohydrate-rich crops, crop residue, weeds)
        - Ethanol is widely added to U.S. gasoline to reduce emissions.
        - Any vehicle on the road today will run well on a 10% ethanol mix.
        - But ethanol made from corn can cause food prices to increase, therefore it is better to use waste plant materials for making ethanol
    - Flexible fuel vehicles: run on 85% ethanol
    - Biodiesel: a fuel produced from vegetable oil, used cooking grease or animal fat used in diesel engines.

 See this animation about Tree Harvesting: Click here.

GEOTHERMAL ENERGY

Geothermal energy uses heat from the earth's internal geologic processes in order to produce electricity or provide heating. One source of geothermal energy is steam. Groundwater percolates down though cracks in the subsurface rocks until it reaches rocks heated by underlying magma, and the heat converts the water to steam. Sometimes this steam makes its way back to the surface in the form of a geyser or hot spring. Wells can be dug to tap the steam reservoir and bring it to the surface, to drive generating turbines and produce electricity. Hot water can be circulated to heat buildings. Regions near tectonic plate boundaries have the best potential for geothermal activity.

The western portion of the United States is most conducive for geothermal energy sources, and over half of the electricity used by the city of San Francisco comes from the Geysers, a natural geothermal field in Northern California. California produces about 50 percent of the world's electricity that comes from geothermal sources.

Entire cities in Iceland, which is located in a volcanically active region near a mid-ocean ridge, are heated by geothermal energy. The Rift Valley region of East Africa also has geothermal power plants. Geothermal energy may not always be renewable in a particular region if the steam is withdrawn at a rate faster than it can be replenished, or if the heating source cools off. The energy produced by the Geysers region of California is already in decline because the heavy use is causing the underground heat source to cool. Geothermal energy recovery can be less environmentally invasive than engaging in recovery methods for non-renewable energy sources. Although it is relatively environmentally friendly, it is not practical for all situations. Only limited geographic regions are capable of producing geothermal energy that is economically viable. Therefore, it will probably never become a major source of energy. The cost and energy requirements for tapping and transporting steam and hot water are high. Hydrogen sulfide, an toxic air pollutant that smells like rotten eggs, is also often associated with geothermal activity.

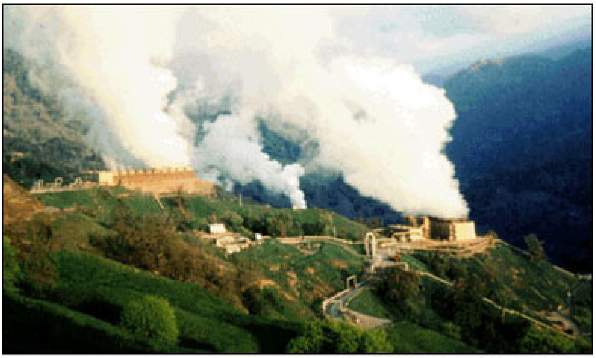


PHOTO CREDIT: JULIE DONNELLY, USGS

THE GEYSERS GEOTHERMAL PLANT

There are 2 ways to harness geothermal heat:

1. Geothermal heat pumps: Utilize the temperature difference between above ground and below ground temperatures

    - Underground temperature stays constant year round (45-75oF)
    - Antifreeze solution circulates from the house / building to the ground
    - The pumps heat buildings in the winter by transferring heat from the ground into buildings.
    - In the summer, heat is transferred through underground pipes from the house / building into the ground.

    Picture of geothermal heat pump from: http://www.energysensene.com/images_EnergySenseNewEngland/GeothermalEnergy1.jpg

2. Geothermal power stations: Harness energy for electricity productions by using hot water heated to high

temperatures in the ground in places where hot magma is closer to the Earth crust (e.g. hot springs or geysers).

- ◦ Geothermal power plants use naturally heated water and steam for direct heating or generating electricity.

  Picture of geothermal power station from: http://academic.evergreen.edu/g/grossmaz/geowells.jpegPicture of geothermal power station from: http://academic.evergreen.edu/g/grossmaz/geowells.jpeg

11. Environmental Health Hazards

MATTHEW R. FISHER

Environmental Health

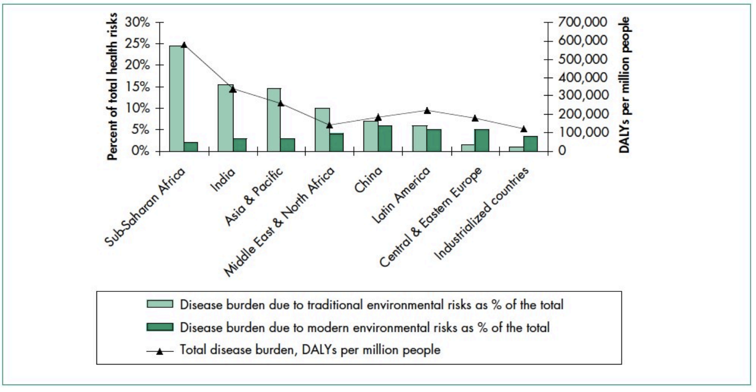
Environmental health is concerned with preventing disease, death and disability by reducing exposure to adverse environmental conditions and promoting behavioral change. It focuses on the direct and indirect causes of diseases and injuries, and taps resources inside and outside the health care system to help improve health outcomes.

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.

Table 1. Typical Environmental Health Issues: Determinants and Health Consequences.

Poverty, Health and Environment

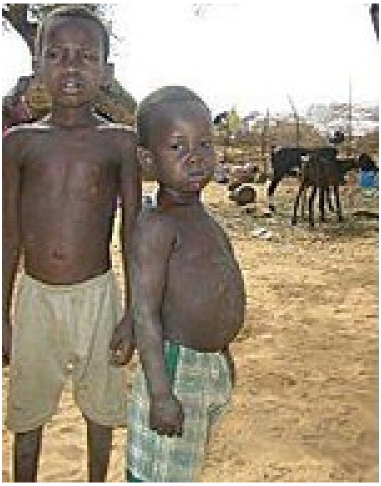
Environmental health risks can be grouped into two broad categories. **Traditional hazards** are related to poverty and the lack of development and mostly affect developing countries and poor people. Their impact exceeds that of modern health hazards by 10 times in Africa, 5 times in Asian countries (except for China), and 2.5 times in Latin America and Middle East. Water-related diseases caused by inadequate water supply and sanitation impose an especially large health burden in Africa, Asia, and the Pacific region. In India alone, over 700,000 children under 5 die annually from diarrhea. In Africa, malaria causes about 500,000 deaths annually. More than half of the world's households use unprocessed *solid fuels*, particularly biomass (crop residues, wood, and dung) for cooking and heating in inefficient stoves without proper ventilation, exposing people—mainly poor women and children—to high levels of indoor air pollution(IAP). IAP causes about 2 million deaths in each year.



Traditional environmental health hazards prevail in developing countries but modern risks are also significant.

Modern hazards, caused by technological development, prevail in industrialized countries where exposure to traditional hazards is low. The contribution of modern environmental risks to the disease burden in most developing countries is similar to – and in quite a few countries, greater than – that in rich countries. Urban air pollution, for example, is highest in parts of China, India and some cities in Asia and Latin America. Poor people increasingly experience a "**double burden**" of traditional and modern environmental health risks. Their total burden of illness and death from all causes per million people is about twice that in rich countries, and the disease burden from environmental risks is 10 times greater.

Environmental Health and Child Survival



Malnourished children in Niger, during the 2005 famine.

Worldwide, the top killers of children under five are acute respiratory infections (from indoor air pollution); diarrheal diseases (mostly from poor water, sanitation, and hygiene); and infectious diseases such as malaria. Children are especially susceptible to environmental factors that put them at risk of developing illness early in life. **Malnutrition** (the condition that occurs when body does not get enough nutrients) is an important contributor to child mortality—malnutrition and environmental infections are inextricably linked. The World Health Organization (WHO) recently concluded that about 50%

of the consequences of malnutrition are in fact caused by inadequate water and sanitation provision and poor hygienic practices.

Poor Water and Sanitation Access

With 1.1 billion people lacking access to safe drinking water and 2.6 billion without adequate sanitation, the magnitude of the water and sanitation problem remains significant. Each year contaminated water and poor sanitation contribute to 5.4 billion cases of diarrhea worldwide and 1.6 million deaths, mostly among children under the age of five. Intestinal worms, which thrive in poor sanitary conditions, infect close to 90 percent of children in the developing world and, depending on the severity of the infection may lead to malnutrition, anemia, or stunted growth. About 6 million people are blind from trachoma, a disease caused by the lack of clean water combined with poor hygiene practices.

Indoor Air Pollution

Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7% of global burden of disease. It is estimated that half of the world's population, mainly in developing countries, uses solid fuels (biomass and coal) for household cooking and space heating. Cooking and heating with such solid fuels on open fires or stoves without chimneys lead to indoor air pollution and subsequently, respiratory infections. Exposure to these health-damaging pollutants is particularly high among women and children in developing countries, who spend the most time inside the household. As many as half of the deaths attributable to indoor use of solid fuel are of children under the age of five.

Malaria

Approximately 40% of the world's people—mostly those living in the world's poorest countries—are at risk from malaria. **Malaria** is an infectious disease spread by mosquitoes but caused by a single-celled parasite called *Plasmodium*. Every year, more than 200 million people become infected with malaria and about 430,000 die, with most cases and deaths found in Sub-Saharan Africa. However, Asia, Latin America, the Middle East, and parts of Europe are also affected. Pregnant women are especially at high risk of malaria. Non-immune pregnant women risk both acute and severe clinical disease, resulting in fetal loss in up to 60% of such women and maternal deaths in more than 10%, including a 50% mortality rate for those with severe disease. Semi-immune pregnant women with malaria infection risk severe anemia and impaired fetal growth, even if they show no signs of acute clinical disease. An estimated 10,000 women and 200,000 infants die annually as a result of malaria infection during pregnancy.

Emerging Diseases

Emerging and re-emerging diseases have been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts. Examples include Ebola virus, West Nile virus, Zika virus, sudden acute respiratory syndrome (SARS), H1N1 influenza; swine and avian influenza (swine, bird flu), HIV, and a variety of other viral, bacterial, and protozoal diseases.

A variety of environmental factors may contribute to re-emergence of a particular disease, including temperature, moisture, human food or animal feed sources, etc. Disease re-emergence may be caused by the coincidence of several of these environmental and/or social factors to allow optimal conditions for transmission of the disease.

Ebola, previously known as Ebola hemorrhagic fever, is a rare and deadly disease caused by infection with one of the Ebola virus strains. Ebola can cause disease in humans and nonhuman primates. The 2014 Ebola epidemic is the largest in history (with over 28,000 cases and 11,302 deaths), affecting multiple countries in West Africa. There were a small number of cases reported in Nigeria and Mali and a single case reported in Senegal; however, these cases were contained, with no further spread in these countries.

The **HIV/AIDS** epidemic has spread with ferocious speed. Virtually unknown 20 years ago, HIV has infected more than 60 million people worldwide. Each day, approximately 14,000 new infections occur, more than half of them among young people below age 25. Over 95 percent of PLWHA (People Living With HIV/AIDS) are in low- and middle- income countries. More than 20 million have died from AIDS, over 3 million in 2002 alone. AIDS is now the leading cause of death in Sub-Saharan Africa and the fourth-biggest killer globally. The epidemic has cut life expectancy by more than 10 years in several nations.

It seems likely that a wide variety of infectious diseases have affected human populations for thousands of years emerging when the environmental, host, and agent conditions were favorable. Expanding human populations have increased the potential for transmission of infectious disease as a result of close human proximity and increased likelihood for humans to be in “the wrong place at the right time” for disease to occur (eg, natural disasters or political conflicts). Global travel increases the potential for a carrier of disease to transmit infection thousands of miles away in just a few hours, as evidenced by WHO precautions concerning international travel and health.

Environmental Toxicology

Environmental toxicology is the scientific study of the health effects associated with exposure to toxic chemicals (Table 1) occurring in the natural, work, and living environments. The term also describes the management of environmental toxins and toxicity, and the development of protections for humans and the environment.

Table 1. The ATSDR 2013 Substance Priority List. The table below lists top 20 substances, in order of priority, which are determined to pose the most significant potential threat to human health. This priority list is not a list of "most toxic" substances but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at various sites.

2013 RANK	NAME
1	ARSENIC
2	LEAD
3	MERCURY
4	VINYL CHLORIDE
5	POLYCHLORINATED BIPHENYLS
6	BENZENE
7	CADMIUM
8	BENZO(A)PYRENE
9	POLYCYCLIC AROMATIC HYDROCARBONS
10	BENZO(B)FLUORANTHENE
11	CHLOROFORM
12	AROCLOR 1260
13	DDT, P,P'-
14	AROCLOR 1254
15	DIBENZO(A,H)ANTHRACENE
16	TRICHLOROETHYLENE
17	CHROMIUM, HEXAVALENT
18	DIELDRIN
19	PHOSPHORUS, WHITE
20	HEXACHLOROBUTADIENE

Routes of Exposure to Chemicals

In order to cause health problems, chemicals must enter your body. There are three main “routes of exposure,” or ways a chemical can get into your body.

- Breathing (inhalation): Breathing in chemical gases, mists, or dusts that are in the air.
- Skin or eye contact: Getting chemicals on the skin, or in the eyes. They can damage the skin, or be absorbed through the skin into the bloodstream.
- Swallowing (ingestion): This can happen when chemicals have spilled or settled onto food, beverages, cigarettes, beards, or hands.

Once chemicals have entered your body, some can move into your bloodstream and reach internal “target” organs, such as the lungs, liver, kidneys, or nervous system.

What Forms do Chemicals Take?

Chemical substances can take a variety of forms. They can be in the form of solids, liquids, dusts, vapors, gases, fibers, mists and fumes. The form a substance is in has a lot to do with how it gets into your body and what harm it can cause. A chemical can also change forms. For example, liquid solvents can evaporate and give off vapors that you can inhale. Sometimes chemicals are in a form that can’t be seen or smelled, so they can’t be easily detected.

What Health Effects Can Chemicals Cause?

An **acute effect** of a contaminant (The term “**contaminant**” means hazardous substances, pollutants, pollution, and chemicals) is one that occurs rapidly after exposure to a large amount of that substance. A chronic effect of a contaminant results from exposure to small amounts of a substance over a long period of time. In such a case, the effect may not be immediately obvious. **Chronic effect** are difficult to measure, as the effects may not be seen for years. Long-term exposure to cigarette smoking, low level radiation exposure, and moderate alcohol use are all thought to produce chronic effects.

For centuries, scientists have known that just about any substance is toxic in sufficient quantities. For example, small amounts of selenium are required by living organisms for proper functioning, but large amounts may cause cancer. The effect of a certain chemical on an individual depends on the dose (amount) of the chemical. This relationship is often illustrated by a dose-response curve which shows the relationship between dose and the response of the individual. **Lethal doses** in humans have been determined for many substances from information gathered from records of homicides, accidental poisonings, and testing on animals.

A dose that is lethal to 50% of a population of test animals is called the **lethal dose-50%** or **LD-50**. Determination of the LD-50 is required for new synthetic chemicals in order to give a measure of their toxicity. A dose that causes 50% of a population to exhibit any significant response (e.g., hair loss, stunted development) is referred to as the **effective dose-50%** or **ED-50**. Some toxins have a threshold amount below which there is no apparent effect on the exposed population.

- Some toxicants can be excreted or metabolized, but fat-soluble toxicants (e.g. heavy metals) are stored in fatty tissues
- Bioaccumulation: toxicants build up in animal tissues
- Biomagnification: toxicants concentrate in top predators
- The result of biomagnifications include:

- Near extinction of peregrine falcons, bald eagles, and brown pelicans
- High PCB levels in polar bears
- Mercury in humans from fish consumption (mercury is released into the environment from various sources e.g. from mines, burning of fossil fuels)
- Figure on the right shows bioaccumulation of PCBs and mercury
- PCB or Polychlorinated biphenyls is used in coolants, paints, cements, PVC plastic etc.

Environmental Contaminants

The contamination of the air, water, or soil with potentially harmful substances can affect any person or community. Contaminants (Table 2) are often chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources. Sometimes harmful environmental contaminants occur biologically, such as mold or a toxic algae bloom.

Table 2. Classification of Environmental Contaminants

Contaminant	Definition
Carcinogen	An agent which may produce cancer (uncontrolled cell growth), either by itself or in conjunction with another substance. Examples include formaldehyde, asbestos, radon, vinyl chloride, and tobacco.
Teratogen	A substance which can cause physical defects in a developing embryo. Examples include alcohol and cigarette smoke.
Mutagen	A material that induces genetic changes (mutations) in the DNA. Examples include radioactive substances, x-rays and ultraviolet radiation.
Neurotoxicant	A substance that can cause an adverse effect on the chemistry, structure or function of the nervous system. Examples include lead and mercury.
Endocrine disruptor	A chemical that may interfere with the body's endocrine (hormonal) system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife. A wide range of substances, both natural and man-made, are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, arsenic, polychlorinated biphenyls (PCBs), DDT and other pesticides, and plasticizers such as bisphenol A (BPA).

An Overview of Some Common Contaminants

Arsenic is a naturally occurring element that is normally present throughout our environment in water, soil, dust, air, and food. Levels of arsenic can regionally vary due to farming and industrial activity as well as natural geological processes. The arsenic from farming and smelting tends to bind strongly to soil and is expected to remain near the surface of the land for hundreds of years as a long-term source of exposure. Wood that has been treated with chromated copper arsenate (CCA) is commonly found in decks and railing in existing homes and outdoor structures such as playground equipment. Some underground aquifers are located in rock or soil that has naturally high arsenic content.

Most arsenic gets into the body through ingestion of food or water. Arsenic in drinking water is a problem in many countries around the world, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the United States. Arsenic may also be found in foods, including rice and some fish, where it is present due to uptake from soil and water. It can also enter the body by breathing dust containing arsenic. Researchers are finding that arsenic, even at low levels, can interfere with the body's endocrine system. Arsenic is also a known human carcinogen associated with skin, lung, bladder, kidney, and liver cancer.

Mercury is a naturally occurring metal, a useful chemical in some products, and a potential health risk. Mercury exists in several forms; the types people are usually exposed to are methylmercury and elemental mercury. Elemental mercury at room temperature is a shiny, silver-white liquid which can produce a harmful odorless vapor. Methylmercury, an organic compound, can build up in the bodies of long-living, predatory fish. To keep mercury out of the fish we eat and the air we breathe, it's important to take mercury-containing products to a hazardous waste facility for disposal. Common products sold today that contain small amounts of mercury include fluorescent lights and button-cell batteries.

Although fish and shellfish have many nutritional benefits, consuming large quantities of fish increases a person's exposure to mercury. Pregnant women who eat fish high in mercury on a regular basis run the risk of permanently damaging their developing fetuses. Children born to these mothers may exhibit motor difficulties, sensory problems and cognitive deficits. Figure 1 identifies the typical (average) amounts of mercury in commonly consumed commercial and sport-caught fish.

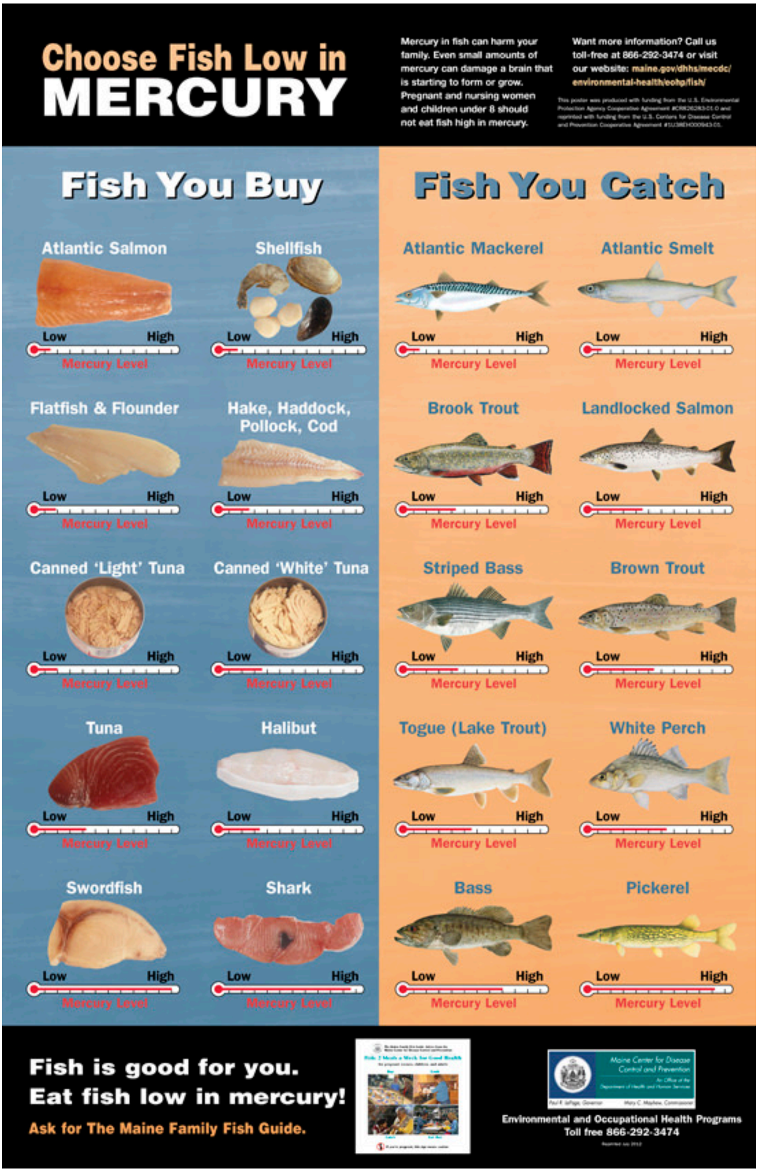


Figure 1. Mercury concentrations in fish can reach potentially dangerous levels (published by the Maine Center for Disease Control & Prevention).

Bisphenol A (BPA) is a chemical synthesized in large quantities for use primarily in the production of polycarbonate plastics and epoxy resins. Polycarbonate plastics have many applications including use in some food and drink packaging, e.g., water and infant bottles, compact discs, impact-resistant safety equipment, and medical devices. Epoxy resins are used as lacquers to coat metal products such as food cans, bottle tops, and water supply pipes. Some dental sealants and composites may also contribute to BPA exposure. The primary source of exposure to BPA for most people is through the diet. Bisphenol A can leach into food from the protective internal epoxy resin coatings of canned foods and from consumer products such as polycarbonate tableware, food storage containers, water bottles, and baby bottles. The degree to which BPA leaches from polycarbonate bottles into liquid may depend more on the temperature of the liquid or bottle, than the age of the container. BPA can also be found in breast milk.

What can I do to prevent exposure to BPA?

Some animal studies suggest that infants and children may be the most vulnerable to the effects of BPA. Parents and caregivers, can make the personal choice to reduce exposures of their infants and children to BPA:

- Don't microwave polycarbonate plastic food containers. Polycarbonate is strong and durable, but over time it may break down from over use at high temperatures.
- Plastic containers have recycle codes on the bottom. Some, but not all, plastics that are marked with recycle codes 3 or 7 may be made with BPA.
- Reduce your use of canned foods.
- When possible, opt for glass, porcelain or stainless steel containers, particularly for hot food or liquids.
- Use baby bottles that are BPA free.

Phthalates are a group of synthetic chemicals used to soften and increase the flexibility of plastic and vinyl. Polyvinyl chloride is made softer and more flexible by the addition of phthalates. Phthalates are used in hundreds of consumer products. Phthalates are used in cosmetics and personal care products, including perfume, hair spray, soap, shampoo, nail polish, and skin moisturizers. They are used in consumer products such as flexible plastic and vinyl toys, shower curtains, wallpaper, vinyl miniblinds, food packaging, and plastic wrap. Exposure to low levels of phthalates may come from eating food packaged in plastic that contains phthalates or breathing dust in rooms with vinyl miniblinds, wallpaper, or recently installed flooring that contain phthalates. We can be exposed to phthalates by drinking water that contains phthalates. Phthalates are suspected to be endocrine disruptors.

Lead is a metal that occurs naturally in the rocks and soil of the earth's crust. It is also produced from burning fossil fuels such as coal, oil, gasoline, and natural gas; mining; and manufacturing. Lead has no distinctive taste or smell. The chemical symbol for elemental lead is Pb. Lead is used to produce batteries, pipes, roofing, scientific electronic equipment, military tracking systems, medical devices, and products to shield X-rays and nuclear radiation. It is used in ceramic glazes and crystal glassware. Because of health concerns, lead and lead compounds were banned from house paint in 1978; from solder used on water pipes in 1986; from gasoline in 1995; from solder used on food cans in 1996; and from tin-coated foil on wine bottles in 1996. The U.S. Food and Drug Administration has set a limit on the amount of lead that can be used in ceramics.

Lead and lead compounds are listed as "reasonably anticipated to be a human carcinogen". It can affect almost every organ and system in your body. It can be equally harmful if breathed or swallowed. The part of the body most sensitive to lead exposure is the central nervous system, especially in children, who are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead can develop brain damage that can cause convulsions and death; the child can also develop blood anemia, kidney damage, colic, and muscle weakness. Repeated low levels of exposure to lead can alter a child's normal mental and physical growth and result in learning or behavioral problems. Exposure to high levels of lead for pregnant women can cause miscarriage, premature births, and smaller babies. Repeated or chronic exposure can cause lead to accumulate in your body, leading to lead poisoning.

Figure 2. Nail products are known to contain toxic chemicals, such as dibutyl phthalate (DBP), toluene, and formaldehyde.

Formaldehyde is a colorless, flammable gas or liquid that has a pungent, suffocating odor. It is a volatile organic compound, which is an organic compound that easily becomes a vapor or gas. It is also naturally produced in small, harmless amounts in the human body. The primary way we can be exposed to formaldehyde is by breathing air containing it. Releases of formaldehyde into the air occur from industries using or manufacturing formaldehyde, wood products (such as particle-board, plywood, and furniture), automobile exhaust, cigarette smoke, paints and varnishes, and carpets and permanent press fabrics. Nail polish, and commercially applied floor finish emit formaldehyde.

In general, indoor environments consistently have higher concentrations than outdoor environments, because many building materials, consumer products, and fabrics emit formaldehyde. Levels of formaldehyde measured in indoor air range from 0.02–4 parts per million (ppm). Formaldehyde levels in outdoor air range from 0.001 to 0.02 ppm in urban areas.

Radiation

Radiation is energy given off by atoms and is all around us. We are exposed to radiation every day from natural sources like soil, rocks, and the sun. We are also exposed to radiation from man-made sources like medical X-rays and smoke detectors. We're even exposed to low levels of radiation on cross-country flights, from watching television, and even from some construction materials. You cannot see, smell or taste radiation. Some types of radioactive materials are more dangerous than others. So it's important to carefully manage radiation and radioactive substances to protect health and the environment.

Radon is a radioactive gas that is naturally-occurring, colorless, and odorless. It comes from the natural decay of uranium or thorium found in nearly all soils. It typically moves up through the ground and into the home through cracks in floors, walls and foundations. It can also be released from building materials or from well water. Radon breaks down quickly, giving off radioactive particles. Long-term exposure to these particles can lead to lung cancer. Radon is the leading cause of lung cancer among nonsmokers, according to the U.S. Environmental Protection Agency, and the second leading cause behind smoking.

12. Urbanization

HANNAH RITCHIE AND MAX ROSER

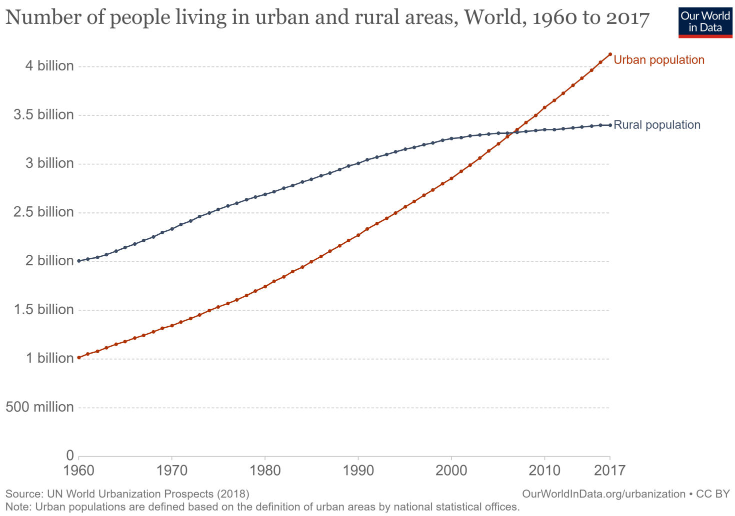
Urbanization Across the World

For most of human history, most people across the world lived in small communities. Over the past few centuries – and particularly in recent decades – this has shifted dramatically. There has been a mass migration of populations from rural to urban areas.

How many people live in urban areas today?

In the visualization we see estimates from the *UN World Urbanization Prospects* on the number of people globally who live in urban and rural areas. In 2017, 4.1 billion people were living in urban areas.

This means over half of the world (55%) live in urban settings. The UN estimates this milestone event – when the number of people in urban areas overtook the number in rural settings – occurred in 2007.

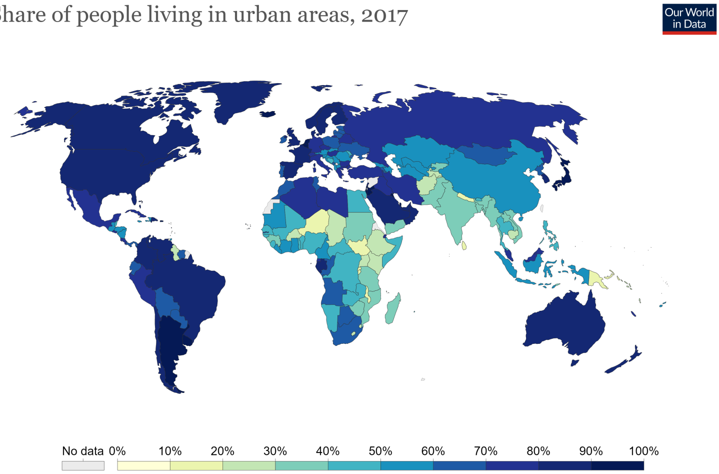


How does the share of people living in urban areas vary between countries?

In the map shown here we see the share of the population that is urbanized across the world.

Across most high-income countries – across Western Europe, the Americas, Australia, Japan and the Middle East – more than 80% of the population live in urban areas. Across most upper-middle income countries – in Eastern Europe, East Asia, North and Southern Africa, and South America – between 50% to 80% of people do. In many low to lower-middle income countries, the majority still live in rural areas.

Share of people living in urban areas, 2017



Source: UN World Urbanization Prospects (2018)
OurWorldInData.org/urbanization • CC BY
Note: Urban populations are defined based on the definition of urban areas by national statistical offices.

What we know about urban populations and why it matters

Before looking in more detail at the differences in estimates of urban populations, we should first clarify what we *do* know:

- globally more people live in urbanized settings than not (disputes in these figures are all above the 50 percent urban mark);
- the broad distribution and density of where people live across the world (sometimes at very high resolution);
- although it can seem like our expanding cities take up a lot of land, only around 1% of global land is defined as built-up area;[1]
- rates of urbanization have been increasing rapidly across all regions (in 1800, less than 10 percent of people across all regions lived in urban areas);
- urbanization is expected to continue to increase with

rising incomes and shifts away from employment in agriculture;[2]
- disagreements in urban population numbers arise from definition or boundary differences in what makes a population 'urban'.

Whilst disagreement on the numbers can seem irrelevant, understanding cities, urbanization rates, the distribution and density of people matters. The allocation and distribution of resources — ranging from housing and transport access to healthcare, education, and employment opportunities — should all be dependent on where people live. Understanding the distribution of people in a given country is essential to make sure the appropriate resources and services are available where they're needed.

The UN's 11th Sustainable Development Goal (SDG) is to "make cities inclusive, safe, resilient and sustainable". If our aim is to develop resource-efficient, inclusive cities, understanding how many people they must provide for is essential for urban planning.

How is an urban area defined?

There is currently no universal definition of what 'urban' means. The UN reports figures based on nationally-defined urban shares. The problem, however, is that countries adopt very different definitions of urbanization. Not only do the thresholds of urban versus rural vary, but the *types* of metrics used also differ. Some countries use minimum population thresholds, others use population density, infrastructure development, employment type, or simply the population of pre-defined cities.

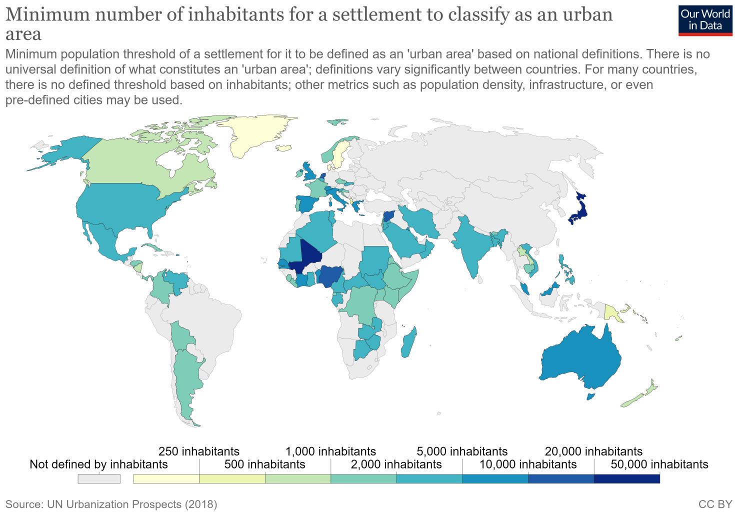
In the table below we highlight the varied definitions across a selection of countries. The UN World Urbanization Prospects database also provides the full downloadable list of statistical definitions for each country.

The table illustrates the broad range of definitions between countries which compromises cross-country comparisons. And since the reported global figure is simply the sum of nationally-reported shares, the lack of a universal definition is also problematic for these aggregated figures.

Even if we could define a single metric to use — such as a minimum population threshold in a settlement — countries adopt very different threshold levels. In the chart below we have mapped the minimum population threshold for countries who adopt this within their definition of 'urban'. 2000 and 5000 inhabitants were jointly the most frequently-adopted threshold. However, the variation across countries was vast. Sweden and Denmark set this threshold at only 200 inhabitants; Japan at 50,000 (a 250-fold difference).

National definitions of ‘urban area’ as used for a custom selection of countries[6]

Country	National definition of ‘urban’
Argentina	Localities with 2,000 inhabitants or more.
Sweden	Built-up areas with 200 inhabitants or more and where houses are at most 200 metres apart.
Japan	Cities defined as shi. In general, shi refers to a municipality that satisfies the following conditions: (1) 50,000 inhabitants or more; (2) 60 per cent or more of the houses located in the main built-up areas; (3) 60 per cent or more of the population (including their dependents) engaged in manufacturing, trade or other urban type of business.
India	Statutory places with a municipality, corporation, cantonment board or notified town area committee and places satisfying all of the following three criteria: (1) 5,000 inhabitants or more; (2) at least 75 per cent of male working population engaged in non-agricultural pursuits; and (3) at least 400 inhabitants per square kilometre.
Zimbabwe	Places officially designated as urban, as well as places with 2,500 inhabitants or more whose population resides in a compact settlement pattern and where more than 50 per cent of the employed persons are engaged in non-agricultural occupations.
Singapore	Entire population.
Uruguay	Cities officially designated as such.



Urbanization over the past 500 years

How has urbanization changed over longer timescales – over the past 500 years?

In the map here we see how the share of populations living in urban areas has changed in recent curies. Data on urban shares dating back to 1500 are available only for select countries, with an estimated share at the global level. Using the timeline on the map (or by clicking on a country) you can see how this share has changed over time.

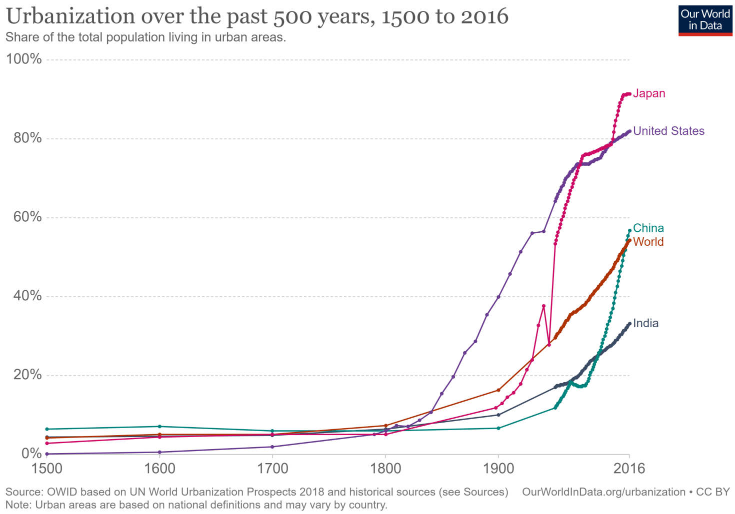
Here we see clearly again that urbanization has largely been confined to the past 200 years. By 1800, still over 90 percent of the global (and country-level) population lived in rural areas. Urbanization in the United States began to increase rapidly through the 19th century, reaching 40 percent by 1900.[10]

By 1950 this reached 64%, and nearly 80% by 2000.

This rate of urbanization was, however, outpaced by Japan. Urban shares in Japan were low until the 20th century.[11]

By 1900, it had just surpassed 1-in-10. This increased rapidly, reaching over half of the population by 1950; nearly 80 percent by 2000, and surpassing the USA to over 90 percent today.

China and India had not dissimilar rates of urbanization until the late 1980s.[12] By then, both had around 1-in-4 living in urban areas. However, China's rate of urbanization increased rapidly over the 1990s, and 2000s. Over this 30-year period its urban share more than doubled to 58 percent. India's rise has continued to steadily rise to 1-in-3 (33 percent) today.



What share of people will live in urban areas in the future?

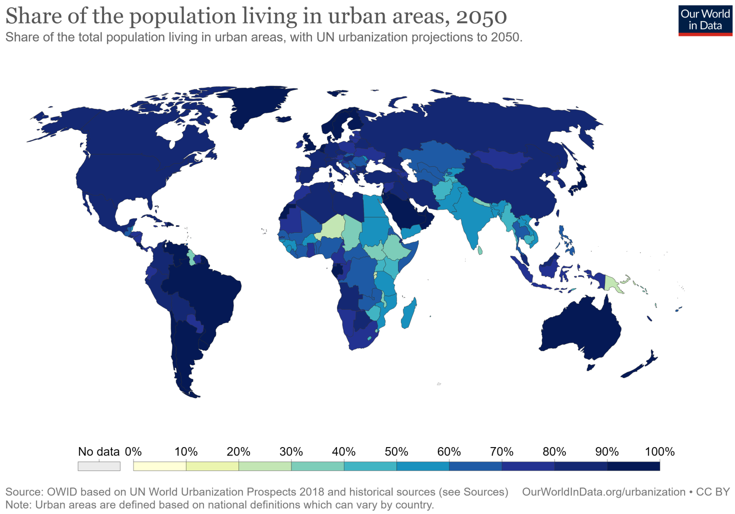
By 2050, more than two-thirds of the world will live in urban areas

The past 50 years in particular have seen a rapid increase in rates of urbanization across the world. Are these trends likely to continue?

The UN World Urbanization Prospects provides estimates of urban shares across the world through to 2050. These projections are shown in the chart — using the timeline you can watch this change over time.

Across all countries urban shares are projected to increase in the coming decades, although at varied rates. By 2050, it's projected that 68 percent of the world's population will live in urban areas (an increase from 54 percent in 2016). In fact, by 2050 there are very few countries where rural shares are expected to be higher than urban. These include several across Sub-Saharan Africa, Asia, Pacific Island States, and Guyana in Latin America.

Why, when most countries are expected to be majority urban, does the global total just over two-thirds? This seems low, but results from the fact that many of the world's most populated countries have comparably low urban shares (either just over half, or less). For example, India (expected to be the world's most populous country), is projected to have an urban share of only 53 percent in 2050.



Urban populations tend to have higher living standards

There are many examples — across broad areas of development — which suggest that, on average, living standards are higher in urban populations than in rural. Some examples include:

- in nearly all countries electricity access is higher in urban areas than in rural areas;
- access to improved sanitation is higher in urban areas;
- access to improved drinking water is higher in urban areas;
- access to clean fuels for cooking and heating is higher in urban areas;
- child malnutrition is lower in urban settings.

Note, however, that it is difficult to infer causality between urbanization and these examples. Since urbanization shows a strong correlation with income, such relationships may instead simply show the effect of higher incomes on electricity access, sanitation, drinking water and nutrition. Furthermore, there can also be significant inequalities within urban areas; this is evidenced by the fact that across many low-to-middle income countries a high share of the urban population live in slum households (which lack access to all of the basic resources).

13. Sustainability

MATTHEW R. FISHER

Environment & Sustainability

The Evolution of Sustainability Itself

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

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

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

17 Goals to Transform Our World

The Sustainable Development Goals are a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere. The 17 Goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the Goals.

- Sustainable development has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

- Sustainable development calls for concerted efforts towards building an inclusive, sustainable and resilient future for people and planet.

- For sustainable development to be achieved, it is crucial to harmonize three core elements: economic growth, social inclusion and environmental protection. These elements are interconnected and all are crucial for the well-being of individuals and societies.

- Eradicating poverty in all its forms and dimensions is an indispensable requirement for sustainable development. To this end, there must be promotion of sustainable, inclusive and equitable economic growth, creating greater opportunities for all, reducing inequalities, raising basic standards of living, fostering equitable social development and inclusion, and promoting integrated and sustainable management of natural resources and ecosystems.

Today, progress is being made in many places, but, overall, action to meet the Goals is not yet advancing at the speed or scale required. 2020 needs to usher in a decade of ambitious action to deliver the Goals by 2030.

With just under ten years left to achieve the Sustainable Development Goals, world leaders at the SDG Summit in September 2019 called for a **Decade of Action** and delivery for sustainable development, and pledged to mobilize financing, enhance national implementation and strengthen institutions to achieve the Goals by the target date of 2030, leaving no one behind.

The UN Secretary-General called on all sectors of society to mobilize for a decade of action on three levels: **global action** to secure greater leadership, more resources and smarter solutions for the Sustainable Development Goals; **local action** embedding the needed transitions in the policies, budgets, institutions and regulatory frameworks of governments, cities and local authorities; and **people action**, including by youth, civil society, the media, the private sector, unions, academia and other stakeholders, to generate an unstoppable movement pushing for the required transformations.

Environmental Equity

While much progress is being made to improve resource efficiency, far less progress has been made to improve resource distribution. Currently, just one-fifth of the global population is consuming three-quarters of the earth's resources (Figure 1). If the remaining four-fifths were to exercise their right to grow to the level of the rich minority it would result in ecological devastation. So far, global income inequalities and lack of purchasing power have prevented poorer countries from reaching the standard of living (and also resource consumption/waste emission) of the industrialized countries.

Figure 1:
Global Consumption Inequality
24 % of the global population — mostly in the high-income countries — accounts for:

92% cars
70% CO_2 emissions
86% copper and aluminium
81% paper
80% iron and steel
48% cereal crops
60% artificial fertilizer

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

Sustainable Ethic

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

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

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

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

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

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

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

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.

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.

Conclusion

The preceding chapters have described how humans have both affected and been affected by the Earth system. Over the next century, human society will have to confront these changes as the scale of environmental degradation reaches a planetary scale. As described throughout this course, human appropriation of natural resources—land, water, fish, minerals, and fossil fuels—has profoundly altered the natural environment. Many scientists fear that human activities may soon push the natural world past any number of tipping points—critical points of instability in the natural Earth system that lead to an irreversible (and undesirable) outcome. This chapter discusses how environmental science can provide solutions to some of our environmental challenges. Solving these challenges does not mean avoiding environmental degradation altogether, but rather containing the damage to allow human societies and natural ecosystems to coexist, avoiding some of the worst consequences of environmental destruction.

Environmental science cannot predict the future, as the future depends on technological and economic choices that will be made over the next century. However, environmental science can help us make better choices, using everything we know about the Earth system to anticipate how different choices will lead to different outcomes.