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Introduction to Environmental Science

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Printed: February 2, 2012

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Sources

UCCP AP Environmental Science Course, WikiBooks - Applied Ecology

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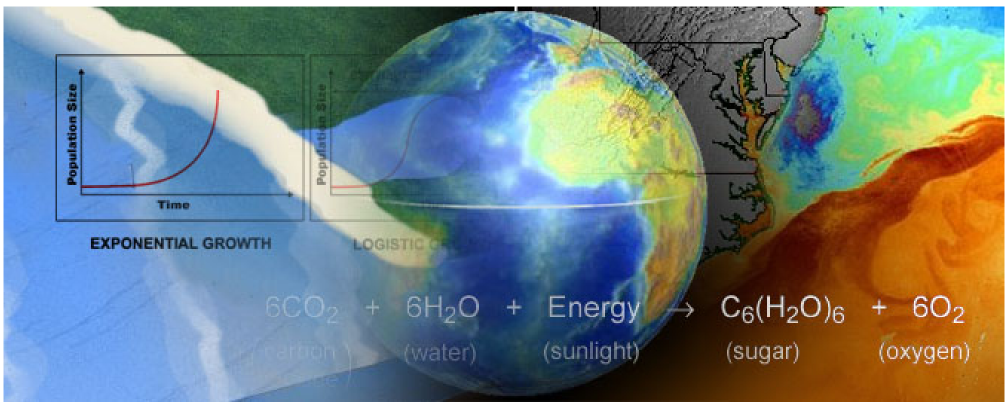
Chapter 1

Introduction to Environmental Science



1.1 Introduction

The environmental conditions of earth, including the climate, are determined by physical, chemical, biological, and human interactions that transform and transport materials and energy. This is the "earth system" that humans rely upon for survival and life. Understanding current environmental issues requires having a critical eye to all information read and found online. **Remember: Junk In = Junk Out.** If you start with false and incorrect information, you will end with false conclusions. Obtaining reliable and credible information is one of the most important steps in evaluating current environmental issues.

Chapter Objectives

- Describe what is Earth System Science.
- Explain recent developments that have changed our view of Earth.
- List the critical thinking methods used to evaluate online sources for credibility.

1.2 Definitions

Environmental Science is the study of ...

The Earth behaves as a system in which oceans, atmosphere and land, and the living and non-living parts therein, are all connected. (Steffen et al, 2004). This **earth system** is a highly complex entity characterized by multiple nonlinear responses and thresholds, with linkages between disparate components. (Jickells, et al, 2005).The Oxford English Dictionary defines a system as:

> A set or assemblage of things connected, associated, or interdependent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to some scheme or plan.

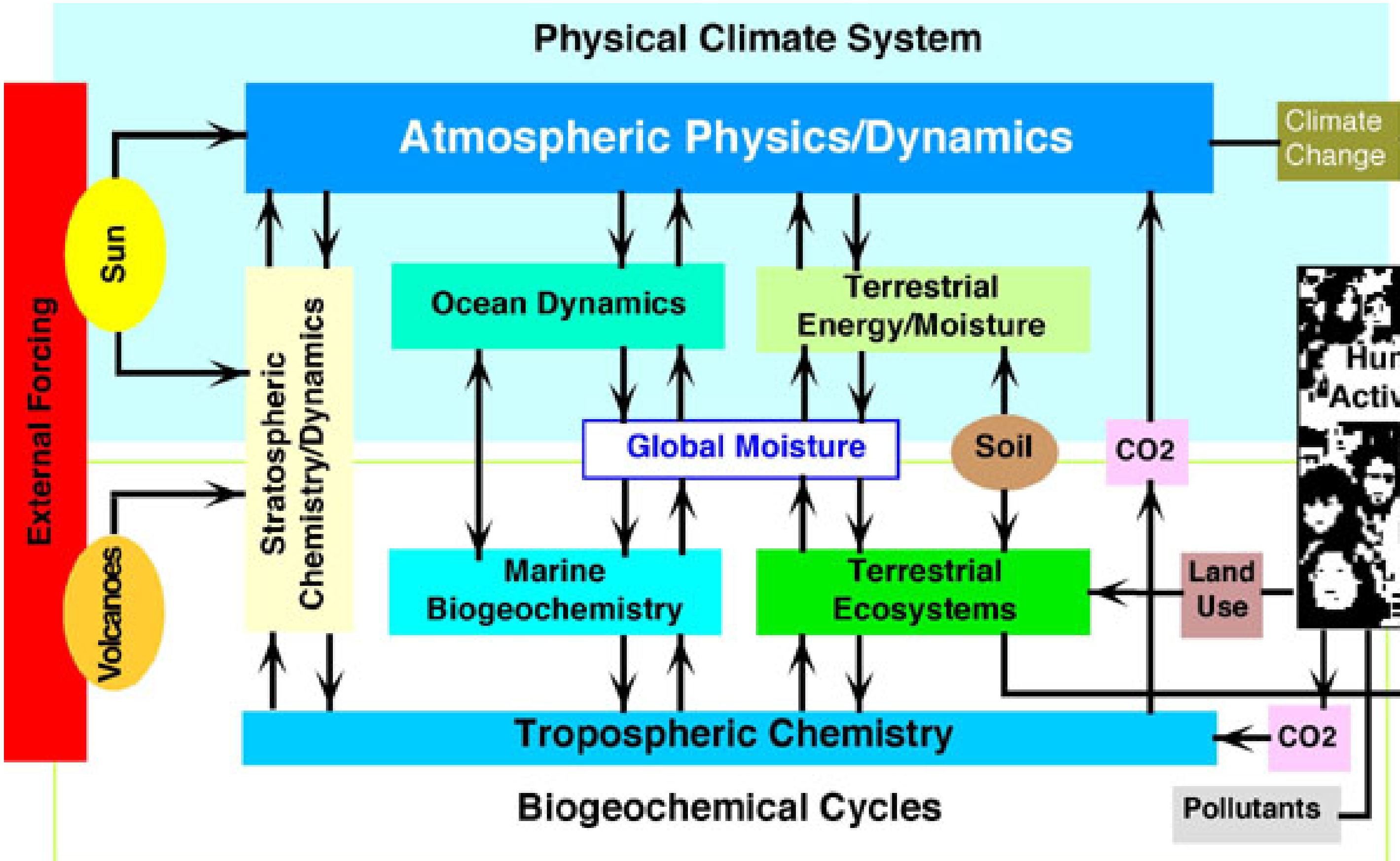
The earth system is composed of interacting physical, chemical, and biological processes that move and change materials and energy on earth. The system provides the conditions necessary for life on the planet. For example, plants, which are part of the living system, use solar energy to change carbon dioxide into organic carbon. Less carbon dioxide in the atmosphere helps cool the planet. Winds and ocean currents move heat from the tropics to higher latitudes, helping to warm the higher latitudes.

Earth systems interact through feedbacks. Positive feedbacks lead to instability. They speed up change in the system. Negative feedbacks lead to stability. They reduce change in the system. Until the beginning of the Anthropocene, or the human era on Earth, the systems were all natural. Now humans have begun to influence the planet, changing the operation of many systems. Because all systems are interconnected, a change in one system influences all other systems.

> ”The goal of earth system science is to obtain a scientific understanding of the entire earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all timescales” (Earth System Science Committee, 1986, p. 26).

History of Earth System Science

Earth system science began in 1983 when the NASA Advisory Council established the Earth System Sciences Committee, which published their revolutionary report Earth System Science: A Program For Global Change in 1988. The committee, chaired by Francis Bretherton, showed for the first time how the many systems interact. The term ”earth system science” was first used by Moustafa Chahine of the NASA Jet Propulsion Laboratory, during a meeting with Bretherton. Chahine noted scientists had studied the solar system for many years, now it was time to study the earth system.



A schematic diagram of the earth system proposed by the Bretherton committee, 1988.

Organizations Studying Earth Systems

The NASA report complements work by many groups that have organized programs to study earth. The primary international groups are:

1. The World Climate Program, established in 1980 under the World Meteorological Organization, theInternational Council for Science, and, since 1993, the Intergovernmental Oceanographic Commission, seeks to develop the fundamental scientific understanding of the physical climate system and climate processes needed to determine to what extent climate can be predicted and the extent of human influence on climate.
2. The Intergovernmental Panel on Climate Change, established in 1988 under the World Meteorological Organization and UNEP, seeks to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.
3. The International Geosphere Biosphere Program, established in 1987 under the International Council for Science, studies the interactions between biological, chemical and physical processes and human systems. IGBP collaborates with other programs to develop and impart the understanding necessary to respond to global change.

Each of these large organizations has many sub-panels working on various aspects of each program. Overall, tens of thousands of scientists contribute to earth-system studies.

Earth Science

The remainder of this page is taken almost entirely from the executive summaries of their reports, especially the report: Global Change and the Earth System: A Planet Under Pressure, IGBP Science 4 Report.

1. The earth is a system that life itself helps to control. Biological processes interact strongly with physical and chemical processes to create the planetary environment, but biology plays a much stronger role than previously thought in keeping earth's environment within habitable limits. Life, the carbon cycle, greenhouse gases in the atmosphere, and earth's surface temperature are all interrelated.
2. Global change is much more than climate change. It is real, it is happening now and it is accelerating. Human activities are significantly influencing the functioning of the earth system in many ways; anthropogenic changes are clearly identifiable beyond natural variability and are equal to some of the great forces of nature in their extent and impact. The changes are so large that we are entering a new geological age, the anthropocene.
3. The human enterprise drives multiple, interacting effects that cascade through the earth system in complex ways. Global change cannot be understood in terms of a simple cause-effect paradigm. Cascading effects of human activities interact with each other and with local- and regional-scale changes in multidimensional ways.
4. The earth's dynamics are characterized by critical thresholds and abrupt changes. Human activities could inadvertently trigger changes with catastrophic consequences for the earth system. Indeed, it appears that such a change was narrowly avoided in the case of depletion of the stratospheric ozone layer. The earth system has operated in different quasi-stable states, with abrupt changes occurring between them over the last half million years. Human activities clearly have the potential to switch the earth system to alternative modes of operation that may prove irreversible. Changes in the earth system can lead to abrupt climate change.
5. The earth is currently operating in a no-analogue state. In terms of key environmental parameters, the earth system has recently moved well outside the range of the natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the earth system, their magnitudes and rates of change are unprecedented.

Table 1.1:

Left: Photograph of earth taken on December 7, 1972 by the crew of Apollo 17 from a distance of about 45,000 km, while traveling to the moon. This image revolutionized our concept of earth, and it is one of the most famous photographs ever taken. Image from NASA Earth Observatory.
Right: The Blue Marble floating in the void. earth as seen from space based on a montage of data from three satellites. Clouds were observed on September 9, 1997 by the Geostationary Operational Environmental Satellite (GOES) operated by NOAA. Land color is portrayed by a vegetation index calculated using data collected from September 9-19, 1997, by the Advanced Very High Resolution Radiometer (AVHRR) instruments carried aboard NOAA's Polar Orbiting Environmental Satellites. Ocean color data were collected in late September and early October 1997 by NASA's Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite. Image from NASA Visualization Analysis Lab, Goddard Space Flight Center.
Global observation systems and fleets of satellites allow us to study the earth as a whole in ways that we could do before only on regional or local scales. We can now study earth as a system.

Recent Developments

Several developments have led to this dramatic change in our perception of earth:

1. **Earth seen from space:** The view of earth from space, a blue-green sphere floating in blackness, triggers emotional feelings of a home teeming with life set in a lifeless void. It also leads us to ponder that we are alone on a spaceship with limited resources. http://oceanworld.tamu.edu/resources/environment-book/Images/firstbluemarble.jpg
2. **Global databases** are now being collected and processed in a consistent way that allows us to compare and analyze processes on a global scale over many years.
3. **Research Advances:** Dramatic advances in our ability to collect data about environmental conditions hundreds to millions of years ago allow contemporary processes to be viewed as continuations

of past processes.

4. **Enhanced computing power** allows us to use theory and data together to study earth and the interactions among many different parts of the earth system.

Science has crossed the threshold of a profound shift in the perception of the human-environment relationship, operating across humanity as a whole and at the scale of the earth as a single system.

1.3 Environmental Issues

As earth's population increases, changes in the environment accelerate, leading ultimately to disasters.

> Wherever humans live at high population densities, making unsustainable demands on natural systems, ... you eventually see ecological breakdowns, unmet needs, and tensions that lead toward conflict. Look at Darfur. Look at Rwanda. Look at Zimbabwe (Quammen, 2005).

1.4 Using the Web

Making good environmental science choices starts with having a good critical eye about environmental science information. Beware what you read on the Internet: Anyone can post to the web. It does not mean they know anything about the topic. **Remember: Junk In = Junk Out.** If you start with false and incorrect information, you will end with false conclusions. Obtaining reliable and **credible information**, or information that is accurate, reviewed by experts, and as unbiased as possible, is one of the most important steps in evaluating current environmental issues.

How do we know which pages on the web can be trusted?

1. Use Scirus to help find scientific articles published in journals and elsewhere: http://www.scirus.com/
2. Use Google Scholar, which only looks up peer-reviewed academic research: http://scholar.google.com/
3. Pay attention to the URL in Internet searches, ***do NOT*** just use the first item that comes up on the first page of Google. Just because it is the first item does not mean it is a reliable or credible source.
4. Use links that end in .edu (accredited educational institution) or .gov (such as Nasa.gov), etc., as opposed .com or .org, which would be a company or organization that may be a reliable source of information, but may not be as well. Just think of how the Tobacco companies hired their own researchers who falsified and hid data for the company so that they could claim that cigarettes were not harmful to one's health.

How do we know what material to trust? Ask these questions:

1. **Who produced the material?**
   - Material produced by an expert tends to be more trustworthy than material produced by others, but one should always review all material with a critical eye.
   - Is there material at the site describing the author's credentials or experience?
   - Is the writer anonymous? This is a bad sign when there is no author listed!
2. **Who uses the material?**
   - Is it cited by others?
   - Is it linked from trustworthy sites?
   - Has the site won awards? Beware of fake awards that some websites give themselves!
3. **Has the material been reviewed by peers?**
   - Journal articles on the web from respected journals are peer reviewed. **Peer review** is when an article or research is first reviewed by several other experts in the field to determine accuracy prior to publishing it. This helps alleviate errors and false data.
   - Some journals are better than others. The best are Science and Nature.
   - Some web pages are reviewed by portals such as the Digital Library for Earth System Education: www.dlese.org
   - Some data sets and information may have been described in published articles cited by the site.
4. **Who hosts the page?**
   - College, university, government, grammar school, commercial, or personal web site? Some domains such as .edu, .org, and .gov are good sources of scientific information.
   - Does the hosting organization have strong opinions? Most organizations are biased. This is neither good nor bad. We just need to be aware of biases. Greenpeace and the US National Marine Fisheries Service may have differing, but valid viewpoints.

5. **When was the web page last updated?**
   - Some sites are many years old.
   - Oceanography is changing rapidly, and often more recent sites have the best information.
6. **False Friends, web pages that mimic scientific sites.**
   - They may be hosted by a non-profit organization.
   - They appear to be written by an expert.
   - They have many references at the end of the article.
   - Yet the information is misleading or incorrect.
   - Sites offering medical advice, advice on diets or nutrition, or cures for common diseases sometimes fall into this category. They are written by medical doctors, they reference obscure journal articles, and they are hosted by the doctor's organization.
   - Consider the controversial topic of chelation therapy to cure clogged arteries. Compare the information on chelation therapy reviewed in an article in the American Heart Journal and a similar article by the American Heart Association with a bibliography of papers supporting chelation therapy by Dr. Elmer Cranton, Medical Director of Mount Ranier Clinic and his article on the Theoretical Mechanism... Who would you believe?
7. **Beware the Widely Quoted Statistic !!**
   - Some statistics are widely quoted by many different authors, yet they may be incorrect or misleading.
   - What is the original source of the statistic?
   - Was the original source reliable.
   - Consider this statistic: Children from low-income households average just 25 hours of shared reading time with their parents before starting school, compared with 1,000 to 1,700 hours for their counterparts from middle-income homes. These oft-repeated numbers originate in a 1990 book by Marilyn Jager Adams titled, "Beginning to Read: Thinking And Learning About Print." Ms. Adams got the 25-hours estimate from a study of 24 children in 22 low-income families. For the middle-income figures, she extrapolated from the experience of a single child: her then-4-year-old son, John. She laid out her calculations and sources carefully over five pages, trying to make clear that she was demonstrating anecdotally the dramatic difference between the two groups. In the 17 years since then, at least a half-dozen child-advocacy groups, including United Way, Kids in Common and Everybody Wins, have boiled down those five pages into a single sentence, repeated in various forms, often without attribution to the original source. As is typical for such numbers, the child-reading stats have taken on a life of their own through a game of media telephone, with news articles usually attributing the numbers to one of these advocacy groups or to various researchers or foundations that themselves got the numbers from the Adams book. For her book, Ms. Adams drew on a 1986 study by William Teale and colleagues of low-income families in Southern California. Using his findings about reading time per child, she extrapolated to their time before entering school and averaged the total. Prof. Teale, who now teaches education at the University of Illinois, Chicago, says his findings couldn't be generalized to the overall population, nor did he ever make that claim: "We had way too small a sample." From Bialik (2007).

1.5 End of Chapter Review & Resources

Lesson Summary

The natural ecosystem processes and environmental resources of Earth are essential for human life. We use them for medicines, food, housing, and well being. After viewing Earth from space we finally recognized that our biosphere and living systems are closed systems that are interconnected. Actions in one system affect all the others. The key to making good decisions about environmental issues is to start with good information. Remember: Junk In = Junk Out. If you start with false information then you will end with false conclusions. Learning how to critically assess and examine all resources used is fundamental to the study of science.

Review Questions

1. In your own words define what an Earth System is.
2. Why is learning about environmental science important?
3. What are some of the most important environmental issues of today?
4. What is a reliable or credible source of information?
5. Why is examining the credibility of information important?
6. What are some of the main items to look for when determining if a source of information is credible?
7. What does Junk In = Junk Out mean? Why is it important to studying science?

Further Reading / Supplemental Links

- World Meteorological Association: www.wmo.int
- International Council for Science: http://www.icsu.org/
- Intergovernmental Oceanographic Commission: http://ioc-unesco.org/
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/
- International Geospere Biosphere Program: http://www.igbp.kva.se/

Vocabulary to Know

- Environmental Science
- Earth System Science
- Peer review
- credible information

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Earth System Science Committee (1986). Earth System Science: A Program For Global Change. Washington DC, NASA. Jickells, T. D., Z. S. An, et al. (2005). Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate. Science 308(5718): 67-71. Quammen, D. (2005). Tracing the Human Footprint. *National Geographic*. September 2005, 208: 2–35.

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Credits

Chapter 2

Scientific Method & Modeling

2.1 The Nature of Science

The goal of science is to learn how nature works by observing the physical world, and to understand it through research and experimentation. Science is a distinctive way of learning about the natural world through observation, inquiry, formulating and testing hypotheses, gathering and analyzing data, and reporting and evaluating findings. We are all part of an amazing and mysterious phenomenon called ”Life” that thousands of scientists everyday are trying to better explain. And it’s surprisingly easy to become part of this great discovery! All you need is your natural curiosity and an understanding of how people use the process of science to learn about the world. The reliability of scientific knowledge comes partly from the objectivity of scientific methods, and also from scientists discussing ideas with each other. In talking with each other, researchers must use more than just their scientific understanding of the world. They must also be able to convince a community of their peers of the correctness of their concepts and ideas.

Chapter Objectives

- List the principles that should guide scientific research.
- Examine a scientist’s view of the world.
- Outline a set of steps that might be used in the scientific method of investigating a problem.
- Explain why a control group is used in an experiment.
- Outline the role that reasoning plays in examining hypotheses.
- Examine the function of the independent variable in an experiment.
- Define what is meant by a theory and compare this to the meaning of hypothesis.
- Outline the need for scientists to be able to share their ideas and findings with each other.
- Identify the role of graphics in presenting results of an investigation.
- Identify the role of peer review in the communication of ideas.
- Examine how ethics are applied to communicating ideas and research.
- Compare scientist to scientist communication to scientist to public communication.
- Identify the benefits of studying science, even if you do not intend on becoming a scientist.
- List three things that can influence scientific research.
- Identify two ways that biotechnology has affected our lives.

2.2 Goals of Science

Science involves objective, logical, and repeatable attempts to understand the principles and forces working in the natural universe. Science is from the Latin word, *scientia,* which means ‘‘knowledge.” Good science is an ongoing process of testing and evaluation. One of the intended benefits for students taking a biology course is that they will become more familiar with the scientific process.

Humans are naturally interested in the world we live in. Young children constantly ask ”why” questions. Science is a way to get some of those ‘‘whys” answered. When we shop for groceries, we are carrying out a kind of scientific experiment (**Figure** 2.1). If you like Brand X of salad dressing, and Brand Y is on sale, perhaps you try Brand Y. If you like Y you may buy it again even when it is not on sale. If you did not like Brand Y, then no sale will get you to try it again. To find out *why* a person makes a particular purchasing choice, you might examine the cost, ingredient list, or packaging of the two salad dressings.

Figure 2.1: Shopping sometimes involves a little scientific experimentation. You are interested in inventing a new type of salad that you can pack for lunch. You might buy a vegetable or salad dressing that you have not eaten before, to discover if you like it. If you like it, you will probably buy it again. That is a type of experiment.

There are many different areas of science, or *scientific disciplines,* but all scientific study involves:

- asking questions
- making observations
- relying on evidence to form conclusions
- being skeptical about ideas or results

Skepticism is an attitude of doubt about the truthfulness of claims that lack empirical evidence. **Scientific skepticism,** also referred to as skeptical inquiry, questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes. Scientific skepticism uses critical thinking to analyze such claims and opposes claims which lack scientific evidence.

A Scientific View of the World

Science is based on the analysis of things that humans can observe either by themselves through their senses, or by using special equipment. Science therefore cannot explain anything about the natural world that is beyond what is observable by current means. The term *supernatural* refers to entities, events, or powers regarded as being beyond nature, in that such things cannot be explained by scientific means. They are not measurable or observable in the same way the natural world is, and so considered to be outside the realm of scientific examination.

When a natural occurrence which was once considered supernatural is understood in the terms of natural causes and consequences, it has a scientific explanation. For example, the flickering lights sometimes seen hovering over damp ground on still evenings or nights are commonly called *Will-o'-the-wisp*. This phenomena looks like a lamp or flame, and is sometimes said to move away if approached. A great deal of folklore surrounds the legend, such as the belief that the lights are lost souls or fairies attempting to lead travelers astray. However, science has offered several potential explanations for Will-o'-the-wisp from burning marsh gases to glowing fungi or animals that glow in a similar way to lightning bugs.

There is no fixed set of steps that scientists always follow and there is no single path that leads to scientific knowledge. There are, however, certain features of science that give it a very specific way of investigating something. You do not have to be a professional scientist to think like a scientist. Everyone, including you, can use certain features of scientific thinking to think critically about issues and situations in everyday life.

Science assumes that the universe is a vast single system in which the basic rules are the same, and thus nature, and what happens in nature, can be understood. Things that are learned from studying one part of the universe can be applied to other parts of the universe. For example, the same principles of motion and gravitation that explain the motion of falling objects on Earth also explain the orbit of the planets around the sun, and galaxies, as shown in **Figure** 2.2. As discussed below, as more and more information and knowledge is collected and understood, scientific ideas can change, still scientific knowledge usually stands the test of time. Science, however, cannot answer all questions.

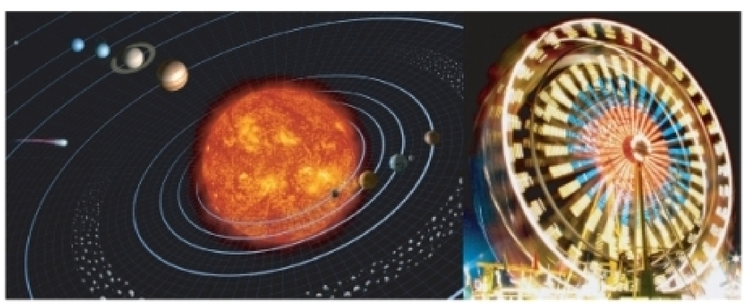


Figure 2.2: With some changes over the years, similar principles of motion have applied to different situations. The same scientific principles that help explain planetary orbits can be applied to the movement of a Ferris wheel.

Nature Can Be Understood

Science presumes that events in the universe happen in patterns that can be understood by careful study. Scientists believe that through the use of the mind, and with the help of instruments that extend the human senses, people can discover patterns in all of nature that can help us understand the world and the universe.

Scientific Ideas Can Change

Science is a process for developing knowledge. Change in knowledge about the natural world is expected because new observations may challenge the existing understanding of nature. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving of theories goes on all the time. Scientists know that even if there is no way to gain complete knowledge about something, an increasingly accurate understanding of nature will develop over time.

The ability of scientists to make more accurate predictions about the natural world, from determining how a cancerous tumor develops a blood supply, to calculating the orbit of an asteroid, provides evidence that scientists are gaining an understanding of how the world works.

Scientific Knowledge Can Stand the Test of Time

Continuity and stability are as much characteristics of science as change is. Although scientists accept some uncertainty as part of nature, most scientific knowledge stands the test of time. A changing of ideas, rather than a complete rejection of the ideas, is the usual practice in science. Powerful ideas about nature tend to survive, grow more accurate and become more widely accepted.

For example, in developing the theory of relativity, Albert Einstein did not throw out Issac Newton's laws of motion but rather, he showed them to be only a small part of the bigger, cosmic picture. That is, the Newtonian laws of motion have limited use within our more general concept of the universe. For example, the National Aeronautics and Space Administration (NASA) uses the Newtonian laws of motion to calculate the flight paths of satellites and space vehicles.

Science Cannot Offer Answers to All Questions

There are many things that cannot be examined in a scientific way. There are, for instance, beliefs that cannot be proved or disproved, such as the existence of supernatural powers, supernatural beings, or the meaning of life. In other cases, a scientific approach to a question and a scientific answer may be rejected by people who hold to certain beliefs.

Scientists do not have the means to settle moral questions surrounding good and evil, or love and hate, although they can sometimes contribute to the discussion of such issues by identifying the likely reasons for certain actions by humans and the possible consequences of these actions.

2.3 The Scientific Method

It can be difficult sometimes to define research methods in a way that will clearly distinguish science from non-science. However, there is a set of core principles that make up the ''bones" of scientific research. These principles are widely accepted within the scientific community and in academia.

We learned earlier in this lesson that there is no fixed set of steps that scientists always follow during an investigation. Similarly, there is no single path that leads scientists to knowledge. There are, however, certain features of science that give it a very specific way of investigating things.

Scientific investigations examine, gain new knowledge, or build on previous knowledge about phenomena. A **phenomenon**, is any occurrence that is observable, such as the burning match shown in **Figure ??**. A phenomenon may be a feature of matter, energy, or time. For example, Isaac Newton made observations of the phenomenon of the moon's orbit. Galileo Galilei made observations of phenomena related to swinging pendulums. Although procedures vary from one field of scientific inquiry to another, certain features distinguish scientific inquiry from other types of knowledge. **Scientific methods** are based on gathering observable, empirical (produced by experiment or observation), and measurable evidence that is critically evaluated. **hypothesis** is a suggested explanation based on evidence that can be tested by observation or experimentation. Experimenters may test and reject several hypotheses before solving a problem. A hypothesis must be testable; it gains credibility by being tested over and over again, and by surviving several attempts to prove it wrong.

The Scientific Method

The scientific method is not a step by step, linear process. It is a way of learning about the world through the application of knowledge. Scientists must be able to have an idea of what the answer to an investigation is. Scientists will often make an observation and then form a hypothesis to explain why a phenomenon occurred. They use all of their knowledge and a bit of imagination in their journey of discovery.

Scientific investigations involve the collection of data through observation, the formation and testing of hypotheses by experimentation, and analysis of the results that involves reasoning.

Scientific investigations begin with observations that lead to questions. We will use an everyday example to show what makes up a scientific investigation. Imagine that you walk into a room, and the room is dark.

- You observe that the room appears dark, and you question why the room is dark.
- In an attempt to find explanations to this phenomenon, you develop several different *hypotheses*. One hypothesis might state that the room does not have a light source at all. Another hypothesis might be that the lights are turned off. Still, another might be that the light bulb has burnt out. Worse yet, you could be going blind.
- To discover the answer, you experiment. You feel your way around the room and find a light switch and turn it on. No light. You repeat the experiment, flicking the switch back and forth; still nothing.
- This means your first two hypotheses, that the room is dark because (1) it does not have a light source; and (2) the lights are off, have been rejected.
- You think of more experiments to test your hypotheses, such as switching on a flashlight to prove that you are not blind.
- In order to accept your last remaining hypothesis as the answer, you could predict that changing the light bulb will fix the problem. If your predictions about this hypothesis succeed (changing the light bulb fixes the problem), the original hypothesis is valid and is accepted.
- However, in some cases, your predictions will not succeed (changing the light bulb does not fix the problem), and you will have to start over again with a new hypothesis. Perhaps there is a short

circuit somewhere in the house, or the power might be out.

The general process of a scientific method is summed up in **Figure** 2.3.

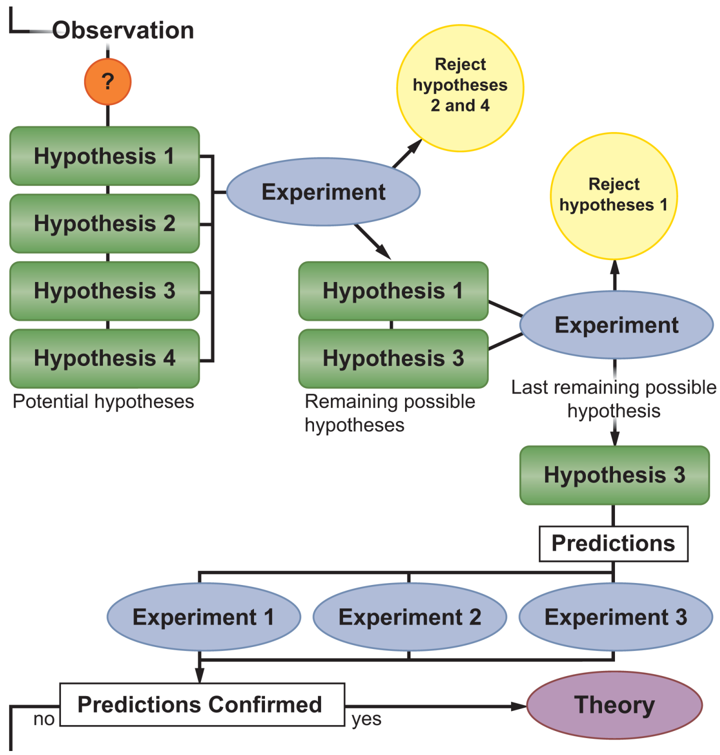


Figure 2.3: The general process of scientific investigations. A diagram that illustrates how scientific investigation moves from observation of phenomenon to a theory. The progress is not as straightforward as it looks in this diagram. Many times, every hypothesis is falsified which means the investigator will have to start over again.

Table 2.1: **Common Terms Used in Scientific Investigations**

Term	Definition
Scientific Method	The process of scientific investigation.
Observation	The act of noting or detecting phenomenon by the senses. For example, taking measurements is a form of observation.
Hypotheses	A suggested explanation based on evidence that can be tested by observation or experimentation.
Scientific Reasoning	The process of looking for scientific reasons for observations.
Experiment	A test that is used to rule out a hypothesis or validate something already known.
Rejected Hypothesis	An explanation that is ruled out by experimentation.
Confirmed Hypothesis	An explanation that is **not** ruled out by repeated experimentation, and makes predictions that are shown to be true.

Table 2.1: (continued)

Term	Definition
Inference	Developing new knowledge based upon old knowledge.
Theory	A widely accepted hypothesis that stands the test of time. Theories are often tested, and usually not rejected.

The Scientific Method Made Easy : http://www.youtube.com/watch?v=zcavPAFiG14&feature=related (9:55).

Making Observations

Scientists first make observations that raise questions. An **observation** is the act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.

Developing Hypotheses

In order to explain the observed phenomenon, scientists develop a number of possible explanations, or *hypotheses.* A hypothesis is a suggested explanation for a phenomenon or a suggested explanation for a relationship between many phenomena. Hypotheses are always based on evidence that can be tested by observation or experimentation. Scientific investigations are required to test hypotheses. Scientists mostly base hypotheses on prior observations or on extensions of existing scientific explanations.

A hypothesis is not really an educated guess. To define a hypothesis as ”an educated guess” is like calling a tricycle a ”vehicle with three.” The definition leaves out the concept’s most important and characteristic feature: the purpose of hypotheses. People generate hypotheses as early attempts to explain patterns observed in nature or to predict the outcomes of experiments. For example, in science, one could correctly call the following statement a hypothesis: identical twins can have different personalities because the environment influences personality.

Evaluating Hypotheses

Scientific methods require hypotheses that are falsifiable, that is, they must be framed in a way that allows other scientists to prove them false. Proving a hypothesis to be false is usually done by observation. However, confirming or failing to falsify a hypothesis does not necessarily mean the hypothesis is true.

For example, a person comes to a new country and observes only white sheep. This person might form the hypothesis: “All sheep in this country are white.” This statement can be called a hypothesis, because it is falsifiable - it can be tested and proved wrong; anyone could falsify the hypothesis by observing a single black sheep, shown in **Figure** below. If the experimental uncertainties remain small (could the person reliably distinguish the observed black sheep from a goat or a small horse), and if the experimenter has correctly interpreted the hypothesis, finding a black sheep falsifies the ”only white sheep” hypothesis. However, you cannot call a failure to find non-white sheep as proof that no non-white sheep exist.

Figure 2.4: The statement

2.4 Scientific Reasoning

Any useful hypothesis will allow predictions based on reasoning. Reasoning can be broken down into two categories: **deduction** and **induction**. Most reasoning in science is done through induction.

Deductive Reasoning (Deduction)

Deduction involves determining a single fact from a general statement; it is only as accurate as the statement.

For example, if the teacher said she checks homework every Monday, she will check homework next Monday.

Deductions are intended to have reasoning that is valid. The reasoning in this argument is valid, because there is no way in which the reasons 1 and 2, could be true and the conclusion, 3, be false:

- Reason 1: All humans are mortal.
- Reason 2: Albert Einstein is a human.
- Conclusion: Albert Einstein is mortal (**Figure** below).

Inductive Reasoning (Induction)

Induction involves determining a general statement that is very likely to be true, from several facts.

For example, if we have had a test every Tuesday for the past three months, we will have a test next Tuesday (and every Tuesday after that).

Induction contrasts strongly with deduction. Even in the best, or strongest, cases of induction, the truth of the reason does not guarantee the truth of the conclusion. Instead, the conclusion of an inductive argument is very likely to be true; you cannot be fully sure it is true because you are making a prediction that has yet to happen.

A classic example of inductive reasoning comes from the philosopher David Hume:

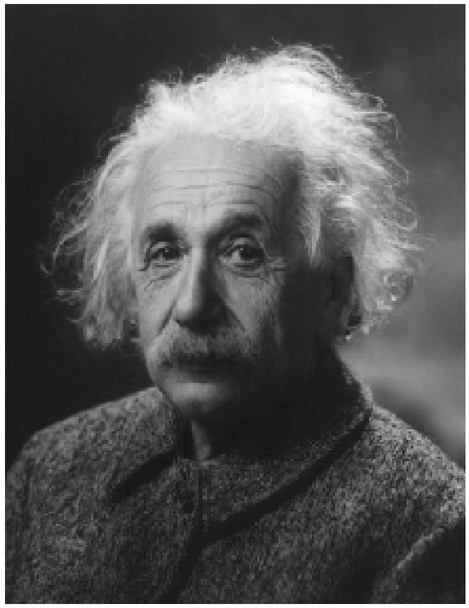


Figure 2.5: Albert Einstein (1879

- Reason: The sun has risen in the east every morning up until now.
- Conclusion: The sun will also rise in the east tomorrow.

Inductive reasoning involves reaching conclusions about unobserved things on the basis of what has been observed already. Inferences about the past from present evidence, such as in archaeology, are induction. Induction could also be across outer space, as in astronomy, where conclusions about the whole universe are drawn from the limited number of things we are able to observe.

2.5 Experimental Design

Experiments

A scientific experiment must have the following features:

- a control, so variables that could affect the outcome are reduced
- the variable being tested reflects the phenomenon being studied
- the variable can be measured accurately, to avoid experimental error
- the experiment must be reproducible.

An **experiment** is a test that is used to eliminate one or more of the possible hypotheses until one hypothesis remains. The experiment is a cornerstone in the scientific approach to gaining deeper knowledge about the physical world. Scientists use the principles of their hypothesis to make predictions, and then test them to see if their predictions are confirmed or rejected.

Scientific experiments involve **controls**, or subjects that are not tested during the investigation. In this way, a scientist limits the factors, or *variables* that can cause the results of an investigation to differ. A **variable** is a factor that can change over the course of an experiment. **Independent variables** are factors whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable). **Dependent variables** change in response to the independent variable. **Controlled variables** are also important to identify in experiments. They are the variables that are kept constant to prevent them from influencing the effect of the independent variable on the dependent variable.

For example, if you were to measure the effect that different amounts of fertilizer have on plant growth, the independent variable would be the amount of fertilizer used (the changing factor of the experiment). The dependent variables would be the growth in height and/or mass of the plant (the factors that are influenced in the experiment). The controlled variables include the type of plant, the type of fertilizer, the amount of sunlight the plant gets, the size of the pots you use. The controlled variables are controlled by you, otherwise they would influence the dependent variable.

In summary:

- The independent variable answers the question "What do I change?"
- The dependent variables answer the question "What do I observe?"
- The controlled variables answer the question "What do I keep the same?"

Controlled Experiments

In an old joke, a person claims that they are snapping their fingers "to keep tigers away," and justifies their behavior by saying, "See, it works!" While this experiment does not falsify the hypothesis "snapping your fingers keeps tigers away," it does not support the hypothesis either, because not snapping your fingers will also keep tigers away. It also follows that not snapping your fingers will not cause tigers to suddenly appear (**Figure** 2.6).

To demonstrate a cause and effect hypothesis, an experiment must often show that, for example, a phenomenon occurs after a certain treatment is given to a subject, and that the phenomenon does not occur in the absence of the treatment.

One way of finding this out is to perform a controlled experiment. In a **controlled experiment,** two identical experiments are carried out side-by-side. In one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.

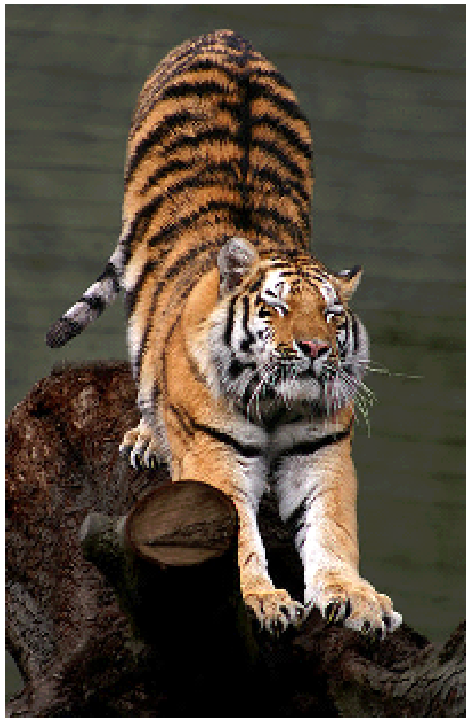


Figure 2.6: Are tigers really scared of snapping fingers, or is it more likely they are just not found in your neighborhood? Considering which of the hypotheses is more likely to be true can help you arrive at a valid answer. This principle, called

A controlled experiment generally compares the results obtained from an experimental sample against a control sample. The control sample is almost identical to the experimental sample except for the one variable whose effect is being tested. A good example would be a drug trial. The sample or group receiving the drug would be the experimental group, and the group receiving the placebo would be the control. A **placebo** is a form of medicine that does not contain the drug that is being tested.

Controlled experiments can be conducted when it is difficult to exactly control all the conditions in an experiment. In this case, the experiment begins by creating two or more sample groups that are similar in as many ways as possible, which means that both groups should respond in the same way if given the same treatment.

Once the groups have been formed, the experimenter tries to treat them identically except for the one variable that he or she wants to study (the independent variable). Usually neither the patients nor the doctor know which group receives the real drug, which serves to isolate the effects of the drug and allow the researchers to be sure the drug does work, and that the effects seen in the patients are not due to the patients believing they are getting better. This type of experiment is called a **double blind** experiment.

Controlled experiments can be carried out on many things other than people; some are even carried out in space! The wheat plants in **Figure** 2.7 are being grown in the International Space Station to study the effects of microgravity on plant growth. Researchers hope that one day enough plants could be grown during spaceflight to feed hungry astronauts and cosmonauts. The investigation also measured the amount of oxygen the plants can produce in the hope that plants could become a cheap and effective way to provide oxygen during space travel.

Figure 2.7: Spaceflight participant Anousheh Ansari holds a miniature wheat plant grown in the Zvezda Service Module of the International Space Station.

Experiments Without Controls

The term **experiment** usually means a controlled experiment, but sometimes controlled experiments are difficult or impossible to do. In this case researchers carry out **natural experiments**. When scientists conduct a study in nature instead of the more controlled environment of a lab setting, they cannot control variables such as sunlight, temperature, or moisture. Natural experiments therefore depend on the scientist's observations of the system under study rather than controlling just one or a few variables as happens in controlled experiments.

For a natural experiment, researchers attempt to collect data in such a way that the effects of all the variables can be determined, and where the effects of the variation remains fairly constant so that the effects of other factors can be determined. Natural experiments are a common research tool in areas of study where controlled experiments are difficult to carry out. Examples include: **astronomy** -the study of stars, planets, comets, galaxies and phenomena that originate outside Earth's atmosphere, **paleontology** - the study of prehistoric life forms through the examination of fossils, and **meteorology** - the study of Earth's atmosphere.

In astronomy it is impossible, when testing the hypothesis "suns are collapsed clouds of hydrogen", to start out with a giant cloud of hydrogen, and then carry out the experiment of waiting a few billion years for it to form a sun. However, by observing various clouds of hydrogen in various states of collapse, and other phenomena related to the hypothesis, such as the nebula shown in **Figure** 2.8, researchers can collect data they need to support (or maybe falsify) the hypothesis.

An early example of this type of experiment was the first verification in the 1600s that light does not travel from place to place instantaneously, but instead has a speed that can be measured. Observation of the appearance of the moons of Jupiter were slightly delayed when Jupiter was farther from Earth, as opposed to when Jupiter was closer to Earth. This phenomenon was used to demonstrate that the difference in the time of appearance of the moons was consistent with a measurable speed of light.

Natural Experiments

There are situations where it would be wrong or harmful to carry out an experiment. In these cases, scientists carry out a natural experiment, or an investigation without an experiment. For example, alcohol

Figure 2.8: The Helix nebula, located about 700 light-years away in the constellation Aquarius, belongs to a class of objects called

can cause developmental defects in fetuses, leading to mental and physical problems, through a condition called fetal alcohol syndrome.

Certain researchers want to study the effects of alcohol on fetal development, but it would be considered wrong or *unethical* to ask a group of pregnant women to drink alcohol to study its effects on their children. Instead, researchers carry out a natural experiment in which they study data that is gathered from mothers of children with fetal alcohol syndrome, or pregnant women who continue to drink alcohol during pregnancy. The researchers will try to reduce the number of variables in the study (such as the amount or type of alcohol consumed), which might affect their data. It is important to note that the researchers do not influence or encourage the consumption of alcohol; they collect this information from volunteers.

Field Experiments

Field experiments are so named to distinguish them from lab experiments. Field experiments have the advantage that observations are made in a natural setting rather than in a human-made laboratory environment. However, like natural experiments, field experiments can get contaminated, and conditions like the weather are not easy to control. Experimental conditions can be controlled with more precision and certainty in the lab.

Predictions

A **prediction** is a statement that tells what will happen under specific conditions. It can be expressed in the form: *If A is true, then B will also be true.* Predictions are based on confirmed hypotheses shown to be true or not proved to be false.

For researchers to be confident that their predictions will be useful and descriptive, their data must have as few errors as possible. **Accuracy** is the measure of how close a calculated or measured quantity is to its actual value. Accuracy is closely related to **precision**, also called reproducibility or repeatability. Reproducibility and repeatability of experiments are cornerstones of scientific methods. If no other researcher can reproduce or repeat the results of a certain study, then the results of the study will not be accepted as valid. Results are called valid only if they are both accurate and precise.

A useful tool to help explain the difference between accuracy and precision is a target, shown in **Figure** 2.9. In this analogy, repeated measurements are the arrows that are fired at a target. Accuracy describes the closeness of arrows to the bulls eye at the center. Arrows that hit closer to the bulls eye are more accurate. Arrows that are grouped together more tightly are more precise.

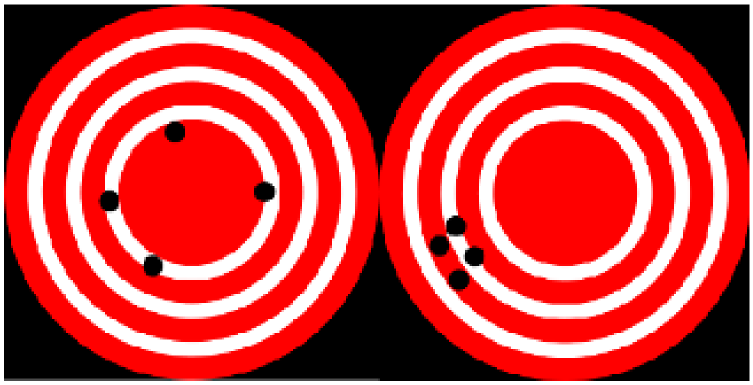


Figure 2.9: A visual analogy of accuracy and precision. Left target: High accuracy but low precision; Right target: low accuracy but high precision. The results of calculations or a measurement can be accurate but not precise; precise but not accurate; neither accurate nor precise; or accurate and precise. A collection of bulls eyes right around the center of the target would be both accurate and precise.

Experimental Error

An **error** is a boundary on the precision and accuracy of the result of a measurement. Some errors are caused by unpredictable changes in the measuring devices (such as balances, rulers, or calipers), but other errors can be caused by reading a measuring device incorrectly or by using broken or malfunctioning equipment. Such errors can have an impact on the reliability of the experiment's results; they affect the accuracy of measurements. For example, you use a balance to obtain the mass of a 100 gram block. Three measurements that you get are: 93.1 g, 92.0 g, and 91.8 g. The measurements are precise, as they are close together, but they are not accurate.

If the cause of the error can be identified, then it can usually be eliminated or minimized. Reducing the number of possible errors by careful measurement and using a large enough sample size to reduce the effect of errors will improve the reliability of your results.

2.6 Scientific Theories

Scientific theories are hypotheses which have stood up to repeated attempts at falsification and are thus supported by a great deal of data and evidence. Some well known biological theories include the theory of evolution by natural selection, the cell theory (the idea that all organisms are made of cells), and the germ theory of disease (the idea that certain microbes cause certain diseases). The scientific community holds that a greater amount of evidence supports these ideas than contradicts them, and so they are referred to as theories.

In every day use, people often use the word **theory** to describe a guess or an opinion. For example, "I have a theory as to why the light bulb is not working." When used in this common way, "theory" does not have to be based on facts, it does not have to be based on a true description of reality. This usage of the word theory often leads to a misconception that can be best summed up by the phrase "It's not a fact, it's only a theory." In such everyday usage, the word is most similar to the term hypothesis.

Scientific theories are the equivalent of what in everyday speech we would refer to as *facts*. In principle, scientific theories are always subject to corrections or inclusion in another, wider theory. As a general rule for use of the term, theories tend to deal with broader sets of phenomena than do hypotheses, which usually deal with much more specific sets of phenomena or specific applications of a theory.

Constructing Theories

In time, a confirmed hypothesis may become part of a theory or may grow to become a theory itself. Scientific hypotheses may be mathematical models. Sometimes they can be statements, stating that some particular instance of the phenomenon under examination has some characteristic and causal explanations. These theories have the general form of universal statements, stating that every instance of the phenomenon has a particular characteristic.

A hypothesis may predict the outcome of an experiment in a laboratory or the observation of a natural phenomenon. A hypothesis should also be falsifiable, and one cannot regard a hypothesis or a theory as scientific if it does not lend itself to being falsified, even in the future. To meet the "falsifiable" requirement, it must at least in principle be possible to make an observation that would disprove the hypothesis. A falsifiable hypothesis can greatly simplify the process of testing to determine whether the hypothesis can be proven to be false. Scientific methods rely heavily on the falsifiability of hypotheses by experimentation and observation in order to answer questions. Philosopher Karl Popper suggested that all scientific theories should be falsifiable; otherwise they could not be tested by experiment.

A **scientific theory** must meet the following requirements:

- it must be consistent with pre-existing theory in that the pre-existing theory has been experimentally verified, though it may often show a pre-existing theory to be wrong in an exact sense
- it must be supported by many strands of evidence rather than a single foundation, ensuring that it is probably a good approximation, if not totally correct.

Also, a theory is generally only taken seriously if it:

- allows for changes to be made as new data are discovered, rather than claiming absolute certainty.
- is the most straight forward explanation, and makes the fewest assumptions about a phenomenon (commonly called "passing the Occam's razor test").

This is true of such established theories as special relativity, general relativity, quantum mechanics, plate tectonics, and evolution. Theories considered scientific meet at least most, but ideally all, of these extra criteria.

In summary, to meet the status of a scientific theory, the theory must be falsifiable or testable. Examples of scientific theories in different areas of science include:

- **Astronomy**: Big Bang Theory
- **Biology**: Cell Theory; Theory of Evolution; Germ Theory of Disease
- **Chemistry**: Atomic Theory; Kinetic Theory of Gases
- **Physics**: General Relativity; Special Relativity; Theory of Relativity; Quantum Field Theory
- **Earth Science**: Giant Impact Theory; Plate Tectonics

Currently Unverifiable Theories

The term theory is sometimes stretched to refer to theoretical speculation which is currently unverifiable. One example is **String theory,** which is a model of physics, which predicts the existence of many more dimensions in the universe than the four dimensions that current science understands (length, width, height, and space-time). A second example is **A theory of Everything,** which is a hypothetical theory in physics that fully explains and links together all known physical phenomena.

For a scientific theory to be valid it must be verified experimentally. Many parts of the string theory are currently untestable due to the large amount of energy that would be needed to carry out the necessary experiments as well as the high cost of conducting them. Therefore string theory may not be tested in the foreseeable future. Some scientists have asked if it even deserves to be called a scientific theory because it is not yet falsifiable (testable).

Superseded Theories

A **superseded,** or obsolete, scientific theory is a theory that was once commonly accepted, but for whatever reason is no longer considered the most complete description of reality by mainstream science. It can also mean a falsifiable theory which has been shown to be false. Giraffes, shown in **Figure** 2.10, are often used in the explanation of Lamarck's superseded theory of evolution. In Lamarckism, a giraffe is able to lengthen its neck over its life time, for example by stretching to reach higher leaves. That giraffe will then have offspring with longer necks. The theory has been superseded by the understanding of natural selection on populations of organisms as the main means of evolution, not physical changes to a single organism over its lifetime.

Scientific Laws

Scientific laws are similar to scientific theories in that they are principles which can be used to predict the behavior of the natural world. Both scientific laws and scientific theories are typically well-supported by observations and/or experimental evidence. Usually scientific laws refer to rules for how nature will behave under certain conditions. Scientific theories are more overarching explanations of how nature works and why it exhibits certain characteristics.

A **physical law** or law of nature is a scientific generalization based on a sufficiently large number of empirical observations that it is taken as fully verified.

Isaac Newton's law of gravitation is a famous example of an established law that was later found not to be universal—it does not hold in experiments involving motion at speeds close to the speed of light or in

Figure 2.10: Superseded theories like Lamarck

close proximity of strong gravitational fields. Outside these conditions, Newton's laws remain an excellent model of motion and gravity.

Scientists never claim absolute knowledge of nature or the behavior of the subject of the field of study. A scientific theory is always open to falsification, if new evidence is presented. Even the most basic and fundamental theories may turn out to be imperfect if new observations are inconsistent with them. Critical to this process is making every relevant part of research publicly available. This allows peer review of published results, and it also allows ongoing reviews, repetition of experiments and observations by many different researchers. Only by meeting these expectations can it be determined how reliable the experimental results are for possible use by others.

2.7 Communicating Ideas

Scientist to Scientist Communication

A wide range of scientific literature is published and it is a format where scientific debates are properly carried out and reviewed. This includes scientific publications that report original research within a scientific field and can comprise of the following:

- scientific articles published in scientific journals
- books written by one or a small number of co-authors who are researchers
- presentations at academic conferences, especially those organized by societies (for example, the American Association for the Advancement of Science)
- government reports
- scientific publications on the internet
- books, technical reports, pamphlets, and working papers issued by individual researchers or research organizations

Scientific journals communicate and document the results of research carried out in universities and various other research institutions. They are like a type of magazine that contains many articles which are written by different researchers about their ideas and discoveries. Most scientific journals cover a single scientific field and publish the research within that field; the research is normally expressed in the form of a scientific paper.

An **academic conference** is a conference for researchers (not always academics) to present and discuss their work. Together with scientific journals, conferences are an important channel for exchange of ideas between researchers. Generally, work is shared in the form of visual posters or short presentations lasting about 10 to 30 minutes. These are usually followed by discussion. A researcher is presenting his work to his peers in **Figure** 2.11.

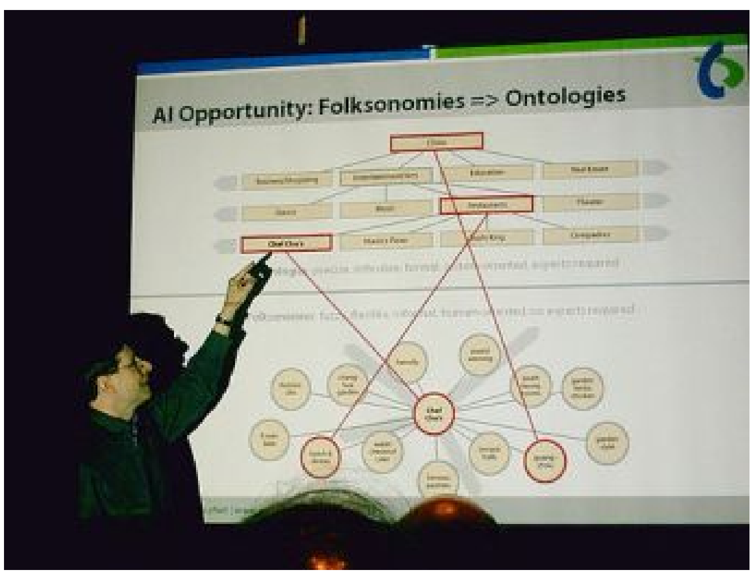


Figure 2.11: A presentation at an academic conference. At conferences, scientists are able to share ideas and their research results with many people at one time, and can talk directly to other researchers and answer their questions.

Types of Scientific Publications: Scientific Journals

A scientific journal is a publication that reports new research, and sometimes contains general science news articles. Most journals are highly specialized for a particular field of research such as biochemistry, microbiology, or botany. However, some of the oldest journals such as *Nature* publish articles and scientific papers across a wide range of scientific fields. The journals shown in **Figure** 2.12 have a similar look and layout to science journals.

Scientific journals contain articles that have been peer reviewed in an attempt to ensure that articles meet the journal's standards of quality, and scientific validity. A scientific journal is not usually read casually as you would read a magazine. Some of the content can be very dense and detailed.

The publication of the results of research is an essential part of the scientific process. The researcher who has written the paper must give enough details about their experiments so that an independent researcher could repeat the experiment to verify the results.

The significance of these different parts of scientific literature differs between science disciplines and has changed over time. Peer-reviewed journal articles remain the most common publication type and have the highest level of trust. However, journals vary enormously in their prestige and importance, and the value of a published article depends on the journal, review process and the degree that it is referenced by other scientists.

Some well known and well respected science and medical journals include:

- Science
- Nature
- Proceedings of the National Academy of Sciences of the United States of America (PNAS)
- Public Library of Science (PLoS)
- Cell
- Journal of the American Medical Association (JAMA)
- The Lancet
- Journal of Theoretical Biology

Science Articles

New research is usually written up in the form of a **scientific article**, which often appear in journals. A scientific article has a standardized structure, which varies only slightly between the different sciences. This format can also be used for your lab reports as part of this class.

It is not really the format of the article that is important, but what lies behind it or the content. However, several key format requirements need to be met by every science article:

1. The title should be short and indicate the contents of the article.

2. The names of all authors that were involved in the research should be given. Where the authors work or study should also be listed.

3. The first section is normally an **abstract**: a one-paragraph summary of the work. The abstract is intended to serve as a quick guide for the reader as to the content of the article.

4. The format should be able to be stored in a library so that scientists years later will be able to recover any document in order to study and assess it

5. The content of the study should be presented in the context of previous scientific investigations, by citing related documents in the existing literature. This is usually in a section called an **introduction**.

Figure 2.12: These research journals publish research papers written by economists, people who study the economy, and related issues. However, the layout of research journals is very similar.

6. Observations that were made, and measurements that were taken are described in a section usually called **Materials and Methods**. The experiments should be described in such a way that other scientists in the same or related fields can repeat the experiments and observations and know whether he or she gets the same results. This is called **reproducibility**.

7. Similarly, the results of the investigation are given in a section called, **results**. Data should be presented in tabular or graphic form (images, charts, graphs, photos, or diagrams, shown in **Figure** 2.13. Graphics should have a caption to explain what they are showing.

8. Interpretation of the meaning of the results is usually addressed in a **discussion** and/or **conclusion** section. The conclusions drawn should be based on previous studies and/or new scientific results. They should also be written in a way such that any reader with knowledge of the field can follow the argument and confirm that the conclusions are sound.

9. Finally, a **references** or **literature cited** section lists the sources cited by the authors in the format required by the journal.

Sources of Information

The reliability of information is dependent on whether the information appears in a primary source, secondary source, or a tertiary source.

Most research studies are first published in a scientific journal, which are referred to as **primary sources**. Technical reports, for minor research results are also primary sources.

Secondary sources include articles in review journals (collections of recent research articles on a topic). Review journals are usually published to highlight advances and new lines of research in specific areas, such as human genetics, specific medical disorders (such as heart disease), neurology (the study of the nervous system) or malacology, (the study of snails and other mollusks). Large projects, broad arguments, or a mix of different types of articles may appear in a book. Review journals and books are referred to

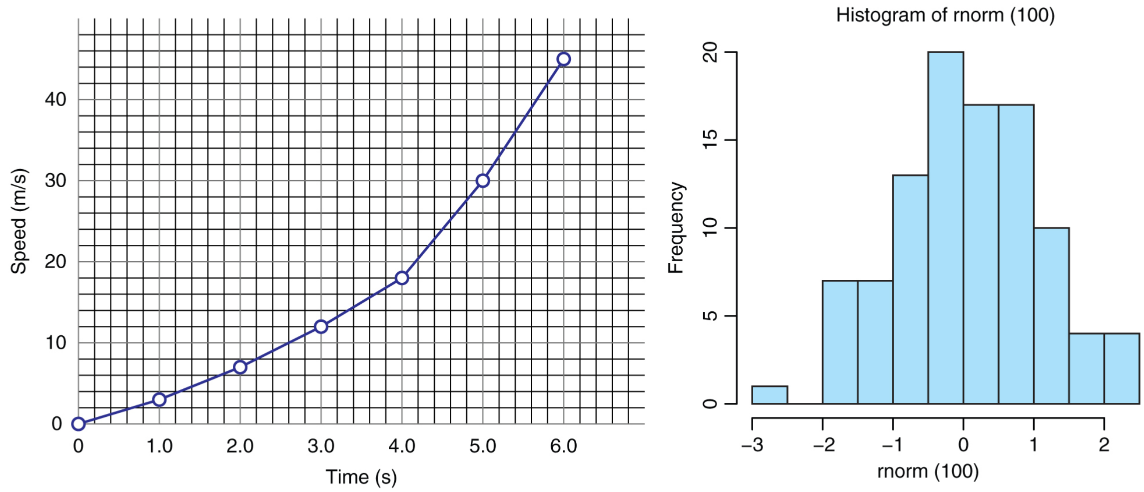


Figure 2.13: Examples of a graph and a chart that can be used to communicate data in scientific papers. (l-r) Graph showing how speed increases over time, Histogram which illustrates the frequency a particular trait appears in a population. Graphics help to illustrate ideas that would otherwise be too confusing to describe in words only.

as secondary sources. Tertiary sources might include encyclopedias and news articles which are generally written for the public to read.

Peer Review

Scientists are expected to report their work truthfully and honestly. They are also expected to have their work reviewed by fellow scientists. This process is called peer review.

Peer review is a process of opening a scientist's research or ideas (in the form of a scientific paper) to examination by other scientists who are experts in the same field. The peer review process aims to make authors meet the standards of their area of study, and to meet the expected standards of science in general. Publications that have not undergone peer review are likely to be regarded with suspicion by scholars and professionals in many fields. However, even peer reviewed journals can contain errors.

A reason for the need for peer review is that it is rare for an individual author or research team to spot every mistake or flaw in a complicated piece of work. The review process provides an opportunity for improvement because a person with special expertise or experience reads the research paper before it is published. Typically, for publication in a science journal, it is also a requirement that the research is new and useful. Since reviewers are normally selected from experts in the areas of science covered by the article, the process of peer review is considered vital to establishing a reliable body of research and knowledge. Therefore, showing work to other scientists increases the likelihood that weaknesses will be found and corrected.

The process of peer review is not designed to detect fraud. As a result, there is usually a large scandal when a researcher and author of a science paper is found to have falsified the research in an article, as many other researchers may have relied upon their original research for their own work or the researcher could have received grant money based on falsified research. Peer review of scientific work assumes that the article reviewed has been honestly written. Usually reviewers do not have full access to the data from which the paper has been written, so they trust that the author is being truthful and honest.

Research Bias

It is important for the researcher to remain neutral or objective when conducting scientific research. A **bias** is a position for favoring one particular point of view over another, and it is usually based on preconceived ideas about a situation. The inability of a human being to remain completely objective is the source of such bias in research. Nevertheless, a researcher or their study is generally said to be *biased* only if the researcher's judgment is influenced by the biases they hold, which could influence their research results.

For example, you want to test whether your dog, Frankie, prefers his regular food or the super expensive brand dog food that you have just bought on sale. You would put each food in a bowl and offer both foods to Frankie at his meal time. However, you secretly hope he prefers his regular food because it is half the price of the more expensive food and you can buy it in the store down the road. Frankie takes a couple of mouthfuls of his regular food, but gobbles up all of the expensive food. You may think, "Well, he did eat some of regular food, so he still likes it," when in fact Frankie clearly preferred the expensive brand. You buy the regular food anyhow. Whether you like it or not, you are biased toward the regular dog food.

This example above is greatly simplified, but, illustrates how personal opinions may influence an investigation.

Another type of bias, called a *systematic bias* is introduced from a flaw in measurements. For example, an incorrectly calibrated thermostat may consistently read several degrees hotter or colder than actual temperature. As a consequence, systematic bias commonly leads to systematic errors in the results of an investigation. Peer review can usually detect systematic biases in a research study.

Conflict of Interest

A **conflict of interest** is a situation in which a researcher has professional or personal interests that are at odds with each other. For example, a researcher is about to investigate a new headache medicine from a drug company called Tinneas. The researcher carries out experiments and finds that the medicine works very well. End of story, right? Not exactly.

Later it is discovered that the researcher owns Tinneas stock. This means he owns part of the company. Even if everything was done correctly during the experiment, and the drug really does work, this researcher has a conflict of interest. As an owner of the company, he will earn money if the drug works, but will lose money if the drug does not work. Therefore, any scientist that may have a reason to favor one particular result from an investigation should not be involved in that investigation.

Competing interests can make it difficult for a person to carry out his or her duties without bias. A conflict of interest exists even if no wrong has been done, or nothing results from it. A conflict of interest can affect the public confidence in the person, a profession, or company.

Scientific Misconduct

When presenting their research to others, an ethical scientist would not falsify results, lie about their results, or plagiarize (steal other peoples ideas or work).

Scientific misconduct is the violation of these standard codes of scholarly conduct and ethical behavior in professional scientific research. Scientific misconduct may take place simply out of reputation. For example, academic scientists are often under enormous pressure to produce publications in peer reviewed journals. Alternatively, there may be commercial or political motivations where the financial or political success of a project depends on publishing evidence of a procedure working or not working. The consequences of scientific misconduct can be severe at a personal and professional level for the people involved. In addition, there are public health concerns attached to the promotion of medical or other procedures that are founded on doubtful research results.

Truth and Honesty in Research and Communication

Some instances of scientific fraud and scientific misconduct have gone through review and were detected only after other groups tried and failed to replicate the published results. An example is the case of physicist Jan Hendrik Schön, in which a total of fifteen papers on microelectronics and nanotechnology were accepted for publication in the top ranked journals, *Nature* and *Science*, following the usual peer review process. All fifteen were found to be fraudulent and were then withdrawn. The fraud was found, not by the peer review process, but by other research groups who tried and failed to reproduce the results of the paper.

Likewise, biomedical scientist Hwang Woo-Suk, rose to fame after claiming a series of breakthroughs in the field of stem cell research. He was once considered one of the pioneering experts in the field of stem cell research, because of his success in creating cloned human embryonic stem cells. However, his two most famous research articles on the cloning experiments were found to contain large amounts of fabricated data. Hwang's papers were retracted (withdrawn from publication), he lost his job at the university where he worked, and also lost his research funding.

2.8 Scientist to Public Communication

Science has become such a part of modern life that it is necessary to communicate the achievements, news, and ambitions of scientists to a wider audience. Scientists need to be able to tell each other and the public about their research and the results of their research. These two groups make up two very different audiences for scientists, however. The first audience is made up of their peers-fellow scientists who have an advanced understand of the technical language and procedures that are involved in scientific investigations. The second audience is made up of members of the public who may or may not understand or know about their research. For example, the following passage is a summary of a paper that appears in the Public Library of Science (PLoS), an online science journal:

A systematic analysis of Alzheimer disease amyloid β peptide variants in *Drosophila* brain demonstrates that their predicted propensity to form protofibrillar aggregates correlates best with toxicity.

Biologists would have no problem understanding the language in this paragraph. However, to a person who is not familiar with this type of science, it may be interpreted as gibberish. In this, lies the challenge for scientists to communicate their research in a way that the general public can understand.

The results of the study could be written in the following way so that a general reader could follow what the researchers meant:

Studies of a particular type of brain protein, called amyloid β peptides, have shown that they can sometimes change into a defective form that resembles sticky clumps. These clumps may become toxic and contribute to Alzheimer's disease, a wasting disease of the brain. Researchers are examining these proteins to find out what exactly causes them to form such clumps. The studies were carried out on fruit flies, which are commonly used as animal models for genetic and biochemical studies of humans.

Communicating to the Public Through the Internet

Many scientists do a good job of presenting their work in an accessible way on the Internet. Scientists and science journalists write news articles that explain the research in everyday language, and can show how the research relates to the reader and to their environment. For example, who would want to read an article that only talked about research that is taking place at the South Pole? An article packed with numbers, units, and percentage rates would be pretty boring to read if it were not related to other areas such the environment, people, animals, or the climate. Also, presenting such academic subjects in a readable and engaging way, allows people to understand what research is being done and why. Such general presentation of science appeals to people because it allows the reader to relate the subject to their life and experiences. For example, both the National Science Foundation (NSF) U.S Antarctic Program and the International Polar Year (IPY) 2007-2008 have websites that explain the types of research that is going on in Antarctica and the Arctic. An NSF research vessel that is taking part in the IPY 2007-2008 is shown in **Figure** 2.14.

A **science magazine** is a publication with news, opinions and reports about science and is written for a non-expert audience. Compare this to a scientific journal, which is written by and for scientific researchers. Science magazines are read by non-scientists and scientists who want accessible information on fields outside their specialization. Articles in science magazines are sometimes republished or summarized by the general press, in newspapers, online news sites, and blogs among other media forms.

Science magazines such as *New Scientist*, shown in **Figure** 2.15, and *Scientific American*, have non-technical summaries of popular areas of research, notable discoveries, and scientific advancements in different fields of research. Science books engage the interest of many more people. So, too, do science websites and science television programming add more images and illustrations that help tell a story. In this way, more people can become more aware of how science effects their lives and become better informed about science subjects.

Figure 2.14: Gentoo penguins watch the Research Vessel Laurence M. Gould in Antarctica. The Gould is one of two research vessels operated by the National Science Foundation and is taking part in the International Polar Year 2007-2008.

Figure 2.15: Cover of

Scientific Consensus

You may have already heard the term *scientific consensus* being used when the subject of global warming is talked about in the news. **Scientific consensus** is the collective judgment, position, and opinion of a community of scientists in a particular field of science, at a particular time. Scientific consensus is not, by itself, a scientific argument, and is not part of the "scientific method". But the topic for which a consensus exists may itself be based on both scientific arguments and scientific methods.

Consensus is normally carried out by scientists talking to each other and sharing their ideas and findings. Scientists can accomplish consensus by giving talks or presentations at conferences, or by publishing their ideas and findings for other scientists to read. This can lead to a situation where those within the field of science can recognize a consensus when it exists, but communicating that to others, such as non-scientists or the public, can be difficult. Sometimes, scientific institutes release statements that are meant to communicate a summary of the science from the inside to the outside. In cases where there is little controversy regarding the subject under study, laying out what the consensus is about can be straightforward.

Nevertheless, scientific consensus may be used in popular or political debate on subjects such as evolution or climate change that are controversial within the public sphere, but are not controversial within the scientific community.

Science and Society

Environmental Science is a science that is very close to our everyday lives. It is a very broad field, covering the intricate workings of chemical processes, to the more broad concepts of ecosystems and global climate change. We are blitzed with headlines about possible health risks from certain toxins and pollutants, the problems of deforestation, and climate change implications. Can an environmental science book give you the answers to these everyday questions? No, but it will enable you learn how to sift through the biases of investigators, the press, and others in a quest to critically evaluate the question. To be honest, five years after you are finished with this book, it is doubtful you would remember all the details within. However, you will have a better idea about where to look for the answer. Knowing about the process of science will also allow you to make a more informed decision. Will you be a scientist? Yes, in a way. You may not be formally trained as a scientist, but you will be able to think critically, solve problems, have some idea about what science can and cannot do, as well as an understanding of the role of biology in your everyday life.

2.9 Environmental Science and You

So why should you study environmental science? Because you are surrounded by it every day! It is about what happens in the world around you. Each human relyies on natural resources and ecosystem processes to produce our food and sustain our communities. Understanding those processes better is a fundamental knowledge base. You may also become a stronger advocate for your community. For example, if a tree planting initiative has begun in your neighborhood, you can investigate the plan for your area and find out what you can do. You could then explain what the program is about to your friends and family. Or, perhaps a city park has fallen into disrepair, and city officials are looking for feedback from the public about what to do with it. You could use scientific thinking to analyze the issue and options, and develop some solutions.

Influences on Scientific Research

To nonscientists, the competition, frustration, cooperation, and disagreement between research scientists can seem disorganized. Scientific knowledge develops from humans trying to figure things out. Scientific research and discoveries are carried out by people—people who have virtues, values, shortcomings, and limitations—just like everyone else. As a result, science and research can be influenced by the values of the society in which the research is carried out. How do such values influence research?

This question is of interest to more than just the scientific community. Science is becoming a larger part of everyone's life, from developing more effective medicines to designing innovative sustainable air conditioning systems that are modeled after the self-cooling nests of termites. The public has become more interested in learning more about the areas of science that affect everyday life. As a result, scientists have become more accountable to a society that expects to benefit from their work.

It costs money to carry out scientific studies. Things such as the cost of equipment, transportation, rent, and salaries for the people carrying out the research all need to be considered before a study can start. The systems of financial support for scientists and their work have been important influences of the type of research and the pace of how that research is conducted. Today, funding for research comes from many different sources, some of which include:

- Government, for example, through the National Institutes of Health (NIH), Center for Disease Control and Prevention (CDC), and the Food and Drug Administration (FDA)
- Military funding (such as through the Department of Defense)
- Corporate sponsorship
- Non-profit organizations, such as the American Cancer Society, Stroke Awareness For Everyone, Inc. (SAFE)
- Private donors

When the economy of a country slows down, the amount of money available for funding research is usually reduced, because both governments and businesses try to save money by cutting out on non-essential expenses.

Science and Ethics

Ethics, also called moral philosophy, is the discipline concerned with what is morally good and bad, right and wrong. The term is also applied to any system or theory of moral values or principles. Personal ethics is the moral code that a person adheres to, while social ethics includes the moral theory that is applied to groups. Bioethics is the social ethics of biology and medicine; it deals with the ethical implications of biological research and applications, especially in medicine. Bioethicists are concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.

While scientific research has produced social benefits, it has also posed some troubling ethical questions. For example, when is it okay to test an experimental cancer drug on people? Developing a new drug takes a long time, maybe as much as 10 years, or more. There are many rules and regulations that drug researchers need to stick to while developing drugs to treat specific illnesses.

Generally, drugs cannot be tested on people until researchers have evidence that the drug does the job that they claim it does (in this case kills cancer cells), but also that the drug will not make patients more ill or cause death. However, if the drug has tested successfully in earlier experiments, and scientists are quite confident that the drug does help kill off cancer cells, is it ethical to allow patients with terminal cancer, who have no other treatment options, to try the experimental drug?

With new challenges in public health and health policy, and with advances in biotechnology, bioethics is a fast-growing academic and professional area of inquiry. Some recent bioethical debates also include:

Refusal of medical treatment The choice of a patient to refuse certain life-saving medical procedures such as a blood transfusion, or refusal by a parent or guardian for medical treatment for the patient.

Euthanasia The choice by a terminally ill person to have medical assistance in dying.

Stem cell research Research involving stem cells, which can be harvested from human embryos.

Animal cloning The ability and usefulness of scientists cloning animals for various needs, such as vaccine development, tissues for transplant into humans such as heart valve, and increased food production. Dolly the sheep, probably the most famous animal clone to date, is shown in **Figure** 2.16.

Figure 2.16: Dolly the sheep is seen here with one of her lambs. In 1997, Dolly was the first mammal to be cloned, and quickly became world-famous. She was euthanized in 2003 after she developed a common, but serious lung disease. To

Because research may have a great effect on the wellbeing of individual people and society in general, scientists are required to behave ethically. Scientists who conduct themselves ethically treat people (called *subjects*) who are involved in their research respectfully. Subjects are not allowed to be exploited deliberately, exposed to harm, or forced to do something they do not agree to.

Science in the Media

A lot of popular science articles come from sources whose aim is to provide a certain amount of entertainment to the reader or viewer. Many popular science articles will examine how a phenomenon relates to people and to their environment. Nevertheless, there is a tendency in the popular media to dilute scientific debates into two sides, rather than cover the complexities and nuances of an issue.

Even well-intentioned scientists can sometimes unintentionally create truth-distorting media firestorms because of journalists' difficulty in remaining critical and balanced, the media's interest in controversy, and the general tendency of science reporting to focus on apparent "groundbreaking findings" rather than on the larger context of a research field. Sometimes scientists will seek to exploit the power of the media. When scientific results are released with great fanfare and limited peer review, the media often requires skepticism and further investigation by skilled journalists and the general public.

The dichloroacetic acid (DCA) story, discussed earlier in this lesson, is an example of what can go wrong when a scientific discovery grasps the public's attention.

An intense amount of public interest was raised by the study and the story received much media attention. As a result, the American Cancer Society and other medical organizations received a large volume of public interest and questions about the ‘‘miracle cure,” DCA.

One of the first stories about the findings contained the headline:

Cheap, 'safe' drug kills most cancers.

The article did explain that the studies were only carried out on cancer cells grown in the lab and in rats. However, the headline may have given some readers the impression that human testing of DCA was complete. People were wildly interested in this new ‘‘cure” to cancer. This prompted the American Cancer Society and other organizations to issue reports that reminded people that although the study results were promising, no formal clinical trials in humans with cancer had yet been carried out. They stressed the need for caution in interpreting the early results. Doctors warned of possible problems if people attempted to try DCA outside a controlled clinical trial. The media received some criticism for the sensation that arose due to their coverage of the discovery.

Therefore, it is important to remember as a member of the public that some popular science news articles can be misleading. A reader can misinterpret the information, especially if the information has a emotional affect on the reader. Also, some articles are written by people who have limited understanding of the subject they are interpreting and can be produced by people who want to promote a particular point of view. Unfortunately, it can be difficult for the non-expert to identify misleading popular science. Sometimes, results are presented in the media without a context, or are exaggerated. Popular science may blur the boundaries between formal science and sensationalism. It is best to analyze such information with skepticism as you would if you were to make an observation in an investigation, and look at the whole context of an issue, rather than just the focus of a particular news item.

For example, in early 1999 West Nile virus, a virus most commonly found in Egypt, was accidentally introduced to New York. Although infection by the virus causes mostly mild or no symptoms in people, in rare instances, West Nile virus can cause inflammation of the brain. The illness, called West Nile Fever, spread across the continent from east to west, carried by infected birds. Mosquitoes spread the disease to mammals. Mosquito larvae (young) are shown in **Figure** 2.17.

There was intense media coverage about the spread of this disease across the United States, and much talk about what this meant for everyone. News coverage of West Nile Fever tended to focus on the serious form of the disease, West Nile Encephalitis, which can cause harmful illness and death. The fact that there is no vaccine for the disease was also emphasized.

However, it is worthwhile considering that until October 2007 there had been a total of 26, 997 confirmed

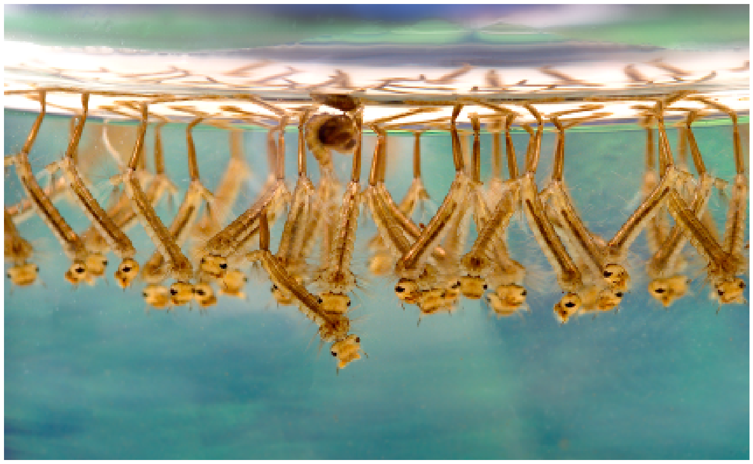


Figure 2.17: Mosquito larvae. As seen on the picture, larvae group together in standing water. The darker structure at the top center of the image is one pupa, another stage of the mosquito lifecycle. Mosquitoes can transfer diseases between animals, including West Nile Fever and malaria. You can avoid mosquito bites by covering your arms and legs while outside during the early morning and late evening, and by applying an insect repellant.

cases of West Nile virus infection, and 1,038 confirmed deaths from the disease. Compare this to the estimated 15 to 60 million people in the United States who are infected with the flu virus every year, and the estimated 36,000 people who die every year from flu complications.

So the next time you are shocked or horrified by a seemingly gloomy forecast in the media, consider how the issue fits into the bigger story.

2.10 Biotechnology: Science Applied to Life

Biotechnology is technology based on biology; it involves the use of organisms or biological processes and can be especially used in agriculture, food science, and medicine. It is the application of biological knowledge to develop tools and products that allow us to control and adapt to our environment.

Biotechnology has effected society and in a number of ways. Although it has been used for centuries in traditional production processes, such as animal breeding shown in **Figure** 2.18, crop growing, and wine making, modern biotechnology is a recent field of science. Bioengineering is the science upon which all biotechnological applications are based. New developments and new approaches are developing at a very fast pace. Biotechnology combines scientific fields such as genetics, molecular biology, biochemistry, and cell biology.

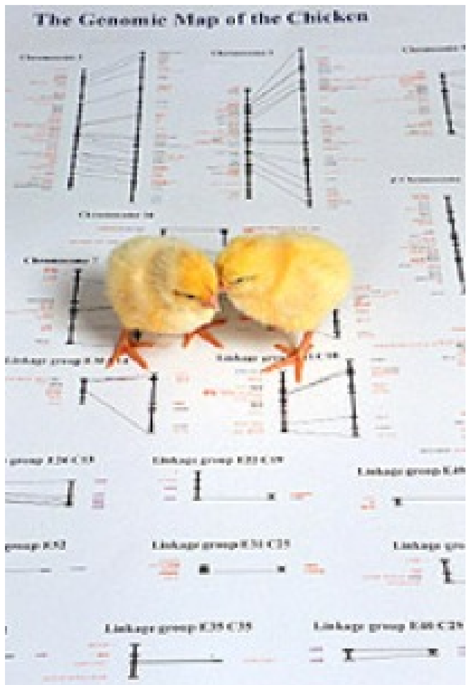


Figure 2.18: Chicks standing on a picture of a genetic map of a chicken. Mapping the genome of organisms is a major part of biotechnology.

The field of modern biotechnology is thought to have largely begun in 1980, when the United States Supreme Court ruled that a genetically-modified microorganism could be patented. Indian-born researcher, Ananda Chakrabarty, had developed a bacterium that was able to break down crude oil, which he proposed to use in treating oil spills.

Applications of Biotechnology

Biotechnology has applications in four major industrial areas, including health care, crop production and agriculture, non-food uses of crops such as biofuels, and environmental uses. One application of biotechnology uses organisms to produce things such as nutritional supplements like vitamins or amino acids, and milk products like cheese, kefir, and yogurt. Biotechnology is also used to recycle, treat waste, and clean up sites contaminated by industrial waste. The use of microorganisms to clean up contaminated sites such as an oil spill is called **bioremediation.**

Medical applications of biotechnology include designing organisms to produce medicines such as antibiotics, or other chemicals. Medical applications for people also include gene therapy which could be used to treat a person who has a genetic disorder such as cystic fibrosis.

An example of an agricultural application is designing plants to grow under specific environmental conditions or in the presence (or absence) of certain chemicals, such as the cress shown in **Figure** 2.19. The cress plant has been genetically modified to turn red only in the presence of nitrogen dioxide, a chemical that is released by landmines and other unexploded bombs. Researchers at the Danish biotechnology company that developed the plant hope that the seeds can be spread over former battleground areas where they will grow and mark the sites of the explosives, thus speeding up the land mine removal process.

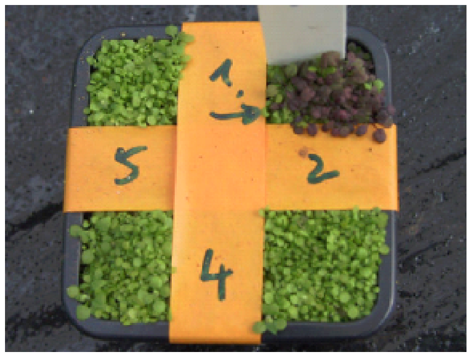


Figure 2.19: This thale cress

Another hope is that biotechnology might produce more environmentally friendly solutions than traditional industrial agriculture. An example of this is the engineering of a plant to express a pesticide, which cuts out the need to apply pesticides to the plants. The corn plants in **Figure** 2.20 have been genetically modified (changed) to produce a toxin that comes from a naturally occurring soil bacterium called *Bacillus thuringiensis.* The Bt toxin kills the pests that eat and destroy corn crops. Whether or not biotechnology products such as this are more environmentally friendly in the long run is a hot topic of debate.

Figure 2.20: People looking at a sign that explains what the genetically modified corn does. In an effort to reduce corn stem-borer infestations, corporate and public researchers came together to develop genetically modified corn varieties suitable for Kenya. The corn plants contain a gene (

2.11 Use of Computers in Science and Medicine

Bioinformatics is an interdisciplinary field which helps solve biological problems using computers. Lots of information is gathered from the mapping of DNA sequences and other related types of research. Bioinformatics allows scientists to gather this information, share it and to use it. It also speeds up the process of analyzing data the scientists have collected. The field may also be called computational biology. Bioinformatics plays a key role in various areas, and it is a key part of the biotechnology and the pharmaceutical industries.

Psychologists David Patterson and Hunter Hoffman of the University of Washington in Seattle developed a virtual world computer game they called "Snow World" shown in **Figure** 2.21, in an effort to reduce the pain experienced by patients undergoing burn treatment and other medical procedures. They found that people who became fully engaged in the virtual reality snow world reported 60 percent less pain. This technology offers a promising new way to manage pain. The researchers say that an interactive digital world may distract us from reality because our minds focus on just a few things at once.

Figure 2.21: A scene from the interactive

Scientific Models

Scientific models are representations of reality. To describe particular parts of a phenomenon, or the interactions among a set of phenomena, it is sometimes helpful to develop a model of the phenomenon. For instance, a scale model of a house or of a solar system is clearly not an actual house or an actual solar system; the parts of an actual house or an actual solar system represented by a scale model are, only in limited ways, representative of the actual objects.

Scientific modeling is the process of making abstract models of natural phenomena. An **abstract model** is a theoretical construct that represents something. Models are developed to allow reasoning within a simplified framework that is similar to the phenomena being investigated. The simplified model may assume certain things that are known to be incomplete in some details. Such assumptions can be useful in that they simplify the model, while at the same time, allowing the development of acceptably accurate solutions. These models play an important role in developing scientific theories.

A **simulation** is a model that runs over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave. It is useful for testing, analysis or training where real-world systems or concepts can be represented by a model. For the scientist, a model also provides a way for calculations to be expanded to explore what might happen in different situations. This method often takes the form of models that can be programmed into computers. The scientist controls the basic assumptions

Figure 2.22: A model of planets of the solar system. This model is clearly not a real solar system; it is a representation of the planets Jupiter, Saturn, Neptune, and Uranus. Scientists use representations of natural things to learn more about them. Also, the visitors to the Griffith Observatory in Los Angeles can get a better idea of the relative sizes of the planets (and Pluto!) by observing this model.

about the variables in the model, and the computer runs the simulation, eventually coming to a complicated answer.

Examples of models include:

- Computer models
- Weather forecast models
- Molecular models
- Climate models
- Ecosystem models
- Geologic models

One of the main aims of scientific modeling is to allow researchers to quantify their observations about the world. In this way, researchers hope to see new things that may have escaped the notice of other researchers. There are many techniques that model builders use which allow us to discover things about a phenomenon that may not be obvious to everyone.

- The National Weather Service Enhanced Radar Images web site (http://radar.weather.gov/) is an excellent example of a simulation. The site exhibits current weather forecasts across the United States.

Evaluating Models

A person who builds a model must be able to recognize whether a model reflects reality. They must also be able to identify and work with differences between actual data and theory.

A model is evaluated mostly by how it reflects past observations of the phenomenon. Any model that is not consistent with reproducible observations must be modified or rejected. However, a fit to observed data alone is not enough for a model to be accepted as valid. Other factors important in evaluating a model include:

- Its ability to explain past observations
- Its ability to predict future observations
- Its ability to control events
- The cost of its use, especially when used with other models
- Ease of use and how it looks

Some examples of the different types of models that are used by science are shown in **Figures** 2.23 and 2.24.

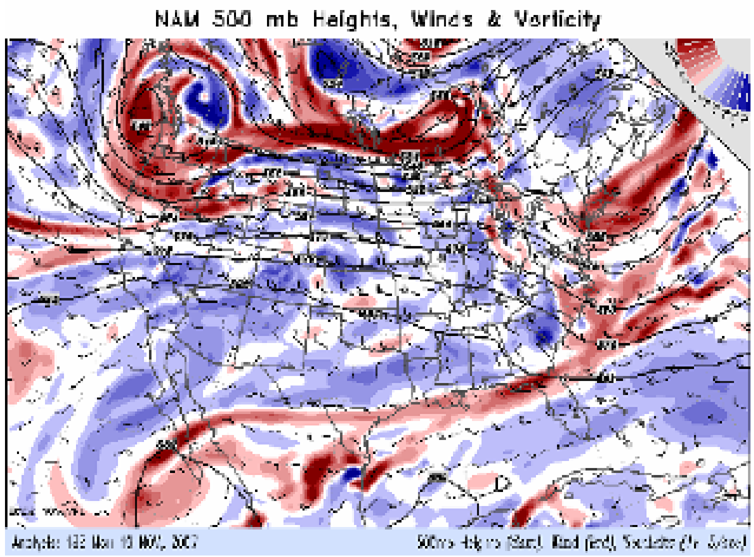


Figure 2.23: A computer model of wind patterns across the continental United States for 19 November, 2007. This model is used to forecast wind speeds and directions. Data on wind speed, direction, and related data are entered into a computer which then produces this simulation. This visual model is much easier for a person to understand than a large table of numbers.

Theories as "Models"

Theories are constructed in order to explain, predict and understand phenomena. This could include the movement of planets, weather patterns, or the behavior of animals, for example. In many instances we are constructing models of reality. A theory makes generalizations about observations and is made up of a related set of ideas and models. The important difference between theories and models is that the first is explanatory as well as descriptive, while the second is only descriptive and predictive in a much more limited sense.

Figure 2.24: Biosphere 2 is an example of a very large three-dimensional model which biologists built to attempt to recreate a self-sustaining biome. To learn more about biomes and ecosystems, go to the

2.12 End of Chapter Review & Resources

Chapter Summary

The reliability of scientific knowledge comes partly from the objectivity of scientific methods, and also from scientists discussing ideas with each other. In talking with each other, researchers must use more than just their scientific understanding of the world. They must also be able to convince other scientists of the accuracy of their ideas. Graphics help to illustrate ideas that would otherwise be too confusing to describe in words only. The peer review process aims to make authors meet the standards of their area of study, and to meet the expected standards of science in general. Ethics is the discipline concerned with what is morally good and bad, right and wrong. Bioethics is the social ethics of biology and medicine; it deals with the ethical implications of biological research and applications, especially in medicine. Bioethicists are concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy. Scientists need to be able to tell each other and the public about their research and the results of their research. These two groups make up two very different audiences for scientists. Presenting academic subjects in a readable and engaging way, allows the general pubic to understand what research is being done and why. Presentation of generally written science appeals to people because it allows the reader to relate the subject to their life and experiences. You cannot be fully informed about the scientific issues you read about unless you understand the science behind the issues, or have the ability to think like a scientist to analyze them. The cost of equipment, transportation, rent, and salaries for the people carrying out the research all need to be considered before a scientific study can start. The systems of financial support for scientists and their work have been important influences of the type of research and the pace of research. Today, funding for research comes from many different sources. Biotechnology is the application of biological knowledge to develop tools and products that allow us to control and adapt to our environment.

Review Questions

1. What is bias in scientific terms and how is it relevant to science?
2. Who do you think the ethical rules about scientific research are aimed toward? Who do they protect?
3. Investigate a science-based societal issue that affects your town, city, or state. Research literature and news reports about the issue, analyzing the data, and examine what an individual person, the community, the local government, or federal government could do about this issue. Present your finding in the form of a poster or computer slide presentation to your class.
4. Find a science article that you believe could be improved upon by adding a graph, a picture, or a drawing. Rewrite the article in your own words, and present it to your class, along with your added graphics.
5. How has biotechnology affected modern life?
6. Science and biotechnology are pursued for different purposes. Do you agree with this statement? Explain your answer.
7. Identify an ethical issue that is raised by biotechnology.
8. Identify an ethical issue that is raised by media coverage of science.
9. Why is it a good idea to study science even if you do not want to become a career scientist?
10. What are three sources of funding for scientific research?
11. How might ethics affect funding for scientific research?
12. Consider the importance of replication in an experiment and how replication of an experiment can affect results.

Further Reading / Supplemental Links

- The National Academies Press - One Being a Scientist: http://www.nap.edu/readingroom/books/obas/
- The University of Washington - The Scientific Method: http://depts.washington.edu/rural/RURAL/design/scim
- The United Nations on Science Ethics: http://www.unesco.org/new/en/social-and-human-sciences/themes/scien and-technology/science-ethics/
- The National Institute of Environmental Health: Ethics in Research - http://www.niehs.nih.gov/research/resourc

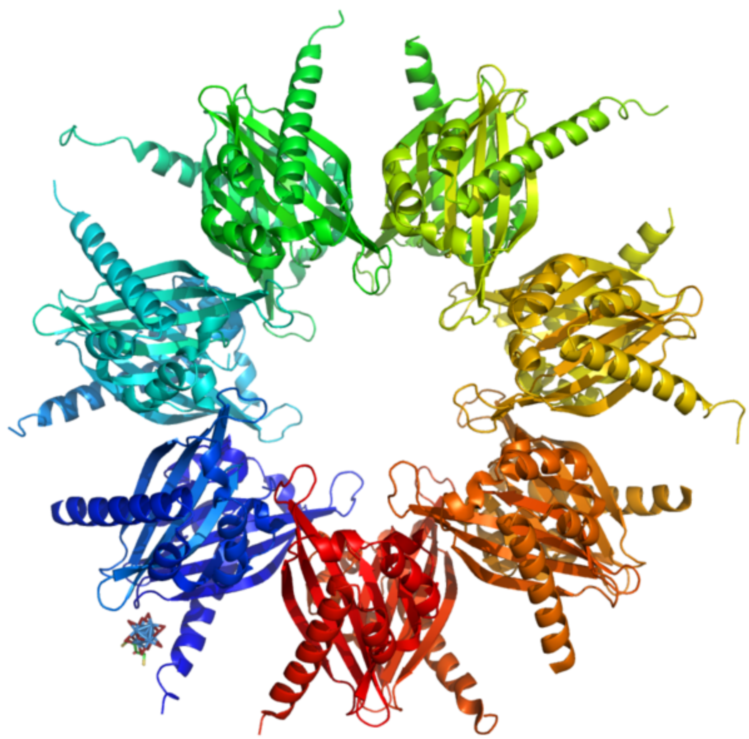
Vocabulary to Know

- **abstract** - A brief, usually one-paragraph, summary of the work.
- **academic conference** - A conference for researchers (not always academics) to present and discuss their work.
- **animal cloning** - The ability and usefulness of scientists cloning animals for various needs, such as vaccine development, tissues for transplant into humans such as heart valve, and increased food production.
- **bioethicists** - People concerned with the ethical questions that arise in the relationships among biology, biotechnology, medicine, politics, law, and philosophy.
- **bioinformatics** - An interdisciplinary field which helps solve biological problems using computers; may also be called computational biology.
- **bioremediation** - The use of microorganisms to clean up contaminated sites, such as an oil spill.
- **biotechnology** - Technology based on biology; it involves the use of organisms or biological processes and can be especially used in agriculture, food science, and medicine.
- **conflict of interest** - A situation in which a researcher has professional or personal interests that are at odds with each other.
- **deduction** - Involves determining a single fact from a general statement.
- **dependent variable** - Changes in response to the independent variable.

- **control** - Something that is not tested during the investigation.
- **controlled experiment** - Two identical experiments are carried out side-by-side; in one of the experiments the independent variable being tested is used, in the other experiment, the control, or the independent variable is not used.
- **controlled variables** - Variables that are kept constant to prevent influencing the effect of the independent variable on the dependent variable
- **ethics** - The discipline concerned with what is morally good and bad, right and wrong.
- **euthanasia** - The choice by a terminally ill person to have medical assistance in dying - Involves determining a single fact from a general statement.
- **dependent variable** - Changes in response to the independent variable.
- **hypothesis** - A suggested explanation based on evidence that can be tested by observation or experimentation.
- **independent variable** - Factor(s) whose values are controlled by the experimenter to determine its relationship to an observed phenomenon (the dependent variable).
- **induction** - Involves determining a general statement that is very likely to be true, from several facts.
- **model** - A physical, mathematical, or logical representation of a system, phenomenon, or process; allows scientists to investigate a phenomenon in a controlled way.
- **observation** - The act of noting or detecting phenomenon through the senses. For example, noting that a room is dark is an observation made through sight.
- **Occam's razor** - States that the explanation for a phenomenon should make as few assumptions as possible.
- **peer review** - The process of opening a scientist's research or ideas (in the form of a scientific paper) to examination by others scientist who are experts in the same field.
- **phenomenon** - Is any occurrence that is observable.
- **reproducibility** - The ability to repeat experiments and get the same results.
- **research scientist** - A person that does scientific investigations and makes discoveries.
- **science magazine** - A publication with news, opinions and reports about science; written for a non-expert audience.
- **scientific article** - A scientific article discussing new research and findings; usually published in a scientific journal.
- **scientific consensus** - The collective judgment, position, and opinion of a community of scientists in a particular field of science, at a particular time.
- **scientific journal** - A publication that communicate and document the results of research carried out in universities and various other research institutions.
- **scientific methods** - Based on gathering observable, empirical (produced by experiment or observation) and measurable evidence that is critically evaluated.
- **scientific misconduct** - The violation of standard codes of scholarly conduct and ethical behavior in professional scientific research.
- **scientific modeling** - The process of making abstract models of natural phenomena.
- **scientific skepticism** - Questions claims based on their scientific verifiability rather than accepting claims based on faith or anecdotes.
- **simulation** - A model that runs over time; brings a model to life and shows how a particular object or phenomenon will behave.
- **stem cell research** - Research involving stem cells, usually harvested from human embryos.
- **systematic bias** - A bias that is introduced from a flaw in measurements.
- **variable** - A factor that can change over the course of an experiment.

Chapter 3

Energy and Chemistry of Life



3.1 Introduction

What do you see when you look at this picture? Is it just a mass of tangled ribbons? Look closely. It's actually a complex pattern of three-dimensional shapes. It represents the structure of a common chemical found inside living cells. The chemical is a protein called kinase. It is involved in many cellular processes. What are proteins? What other chemicals are found in living things? Why does water matter for life? How is energy important? You will learn the answers to these questions as you read this chapter.

Chapter Objectives

- Describe the six different forms of energy and the type of work done by each form.

- Discuss the roles of sources and sinks in an energy budget.
- Define the Law of Conservation of Energy, and explain how the operation of fuel cell vehicles illustrates this principal.
- Name the units with which energy, power, and force are measured and described.
- Use energy flow within a house to explain both theoretical and practical aspects of energy use and conservation.Define elements and compounds.
- Explain why carbon is essential to life on Earth.
- Describe the structure and function of the four major types of organic compounds
- Describe what happens in chemical reactions.
- State the role of energy in chemical reactions.
- Explain the importance of enzymes to living organisms.
- Describe the distribution of Earth's water.
- Identify water's structure and properties.
- Define acids, bases, and pH.
- Explain why water is essential for life.

3.2 Energy

Energy is the ability to do work. **Work** is done when a force is applied to an object over a distance. Any moving object has kinetic energy or energy of motion, and it thus can do work. Similarly, work has to be done on an object to change its kinetic energy. The **kinetic energy** of an object of mass m and speed v is given by the relation E = 1/2 mv2. Sometimes energy can be stored and used at a later time. For example, a compressed spring and water held back by a dam both have the potential to do work. They are said to possess potential energy. When the spring or water is released its **potential energy** is transformed into kinetic energy and other forms of energy such as heat. The energy associated to the gravitational force near the surface of the earth is potential energy. Other forms of energy are really combinations of kinetic and potential energy. Chemical energy, for example, is the electrical potential energy stored in atoms. Heat energy is a combination of the potential and kinetic energy of the particles in a substance.

Forms of Energy

Table 3.1:

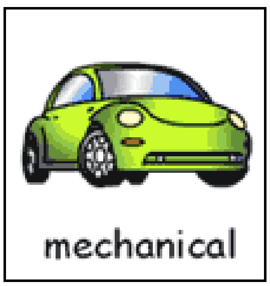
	**Mechanical energy** puts something in motion. It moves cars and lifts elevators. A machine uses mechanical energy to do work. The mechanical energy of a system is the sum of its kinetic and potential energy. Levers, which need a fulcrum to operate, are the simplest type of machine. Wheels, pulleys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

Table 3.2:

Table 3.3:

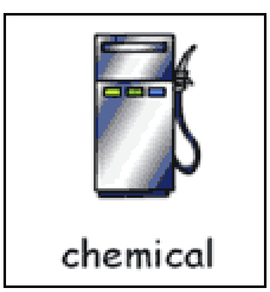
	**Chemical energy** is the energy stored in molecules and chemical compounds, and is found in food, wood, coal, petroleum and other fuels. When the chemical bonds are broken, either by combustion or other chemical reactions, the stored chemical energy is released in the form of heat or light. For example,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

Table 3.4:

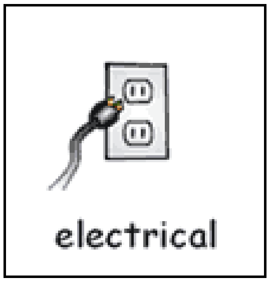
	**Electrical energy** is produced when unbalanced forces between electrons and protons in atoms create moving electrons called electric currents. For example, when we spin a copper wire through the poles of a magnet we induce the motion of electrons in the wire and produce electricity. Electricity can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

Table 3.5:

Table 3.6:

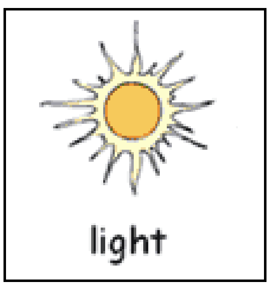
	**Radiant energy** is carried by waves. Changes in the internal energy of particles cause the atoms to emit energy in the form of electromagnetic radiation which includes visible light, ultraviolet (UV) radiation, infrared (IR) radiation, microwaves, radio waves, gamma rays, and X-rays. Electromagnetic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

Table 3.7:

Table 3.8:

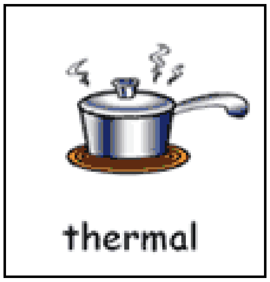
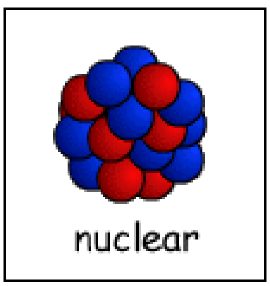
	**Thermal energy** or **Heat energy** is related to the motion or vibration of molecules in a substance. When a thermal system changes, heat flows in or out of the system. Heat energy flows from hot bodies to cold ones. Heat flow, like work, is an energy transfer. When heat flows into a substance it may increase the kinetic energy of the particles and thus elevate its temperature. Heat flow may also change the arrangement of the particles making up a substance by increasing their potential energy. This is what happens to water when it reaches a temperature of 100ºC. The molecules of water move further away from each other, thereby changing the state of the water from a liquid to a gas. During the phase transition the temperature of the water does not change.
	**Nuclear Energy** is energy that comes from the binding of the protons and neutrons that make up the nucleus of the atoms. It can be released from atoms in two different ways: nuclear fusion or nuclear fission. In **nuclear fusion**, energy is released when atoms are combined or fused together. This is how the sun produces energy. In **nuclear fission**, energy is released when atoms are split apart. Nuclear fission is used in nuclear power plants to produce electricity. Uranium 235 is the fuel used in most nuclear power plants because it undergoes a chain reaction extremely rapidly, resulting in the fission of trillions of atoms within a fraction of a second. See this link to view a video about nuclear fission: http://www.ucopenaccess.org/mod/resource/view.php?id=220

Table 3.9:

 See this video about energy: http://www.ucopenaccess.org/mod/resource/view.php?id=22080

Energy Sources and Sinks

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

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

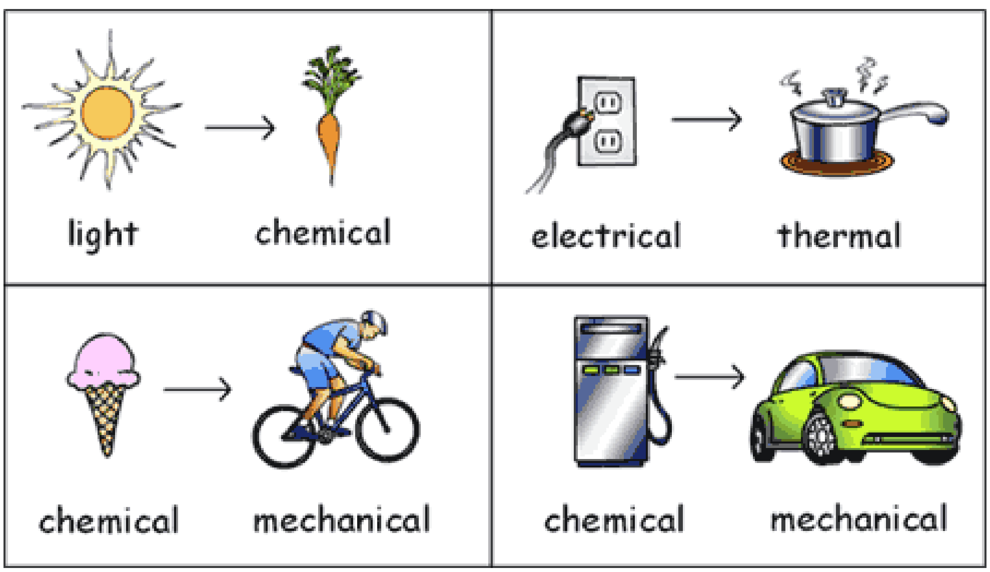
An **energy sink** is anything that collects a significant quantity of energy that is either lost or not considered transferable in the system under study. Sources and sinks have to be included in an energy budget when accounting for the energy flowing into and out of a system.

(Source: US Department of Energy)

3.3 Laws of Thermodynamics : Conservation of Energy

Thermodynamics is the study of energy. Though energy can be converted from one form to another, energy cannot be created or destroyed. 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.* For example, in a motorcycle, the chemical potential energy of the fuel changes to kinetic energy. In a radio, electricity is converted into kinetic energy and wave energy (sound). Machines can be used to convert energy from one form to another. Though ideal machines conserve the mechanical energy of a system, some of the energy always turns into heat when using a machine. For example, heat generated by friction is hard to collect and transform into another form of energy. In this situation, heat energy is usually considered unusable or lost.

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. As you just learned, energy can be condensed (high quality) or dispersed (low quality). Let us look at the example of wood. Many years of growing has fixed/stored energy into the wood of the tree. When it is burned then the energy changes into new forms (such as heat, smoke, and ashes) and is dissipated and lost into the surrounding environment. These new forms of energy are less condensed, and lower-quality energy forms than the wood originally held.



http://www.ucopenaccess.org/mod/resource/view.php?id=22093

3.4 Energy Units

In the International System of Units (SI), the unit of work or energy is the **Joule** (J). For very small amounts of energy, the erg (erg) is sometimes used. An **erg** is one ten millionth of a Joule:

1 Joule = 10,000,000 ergs

Power is the rate at which energy is used. The unit of power is the **Watt** (W), named after James Watt, who perfected the steam engine:

1 Watt = 1 Joule/second

Power is sometimes measured in **horsepower** (hp):

1 horsepower = 746 Watts

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

1 kilowatt-hour = 3,600,000 Joules

It is important to realize that a kilowatt-hour is a unit of energy not power. For example, an iron rated at 2000 Watts would consume 2 x 3.6 10^6 J of energy in 1 hour.

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

1 calorie = 4.189 Joules

An old, but still used unit of heat is the **British Thermal Unit (BTU)**. It is defined as the heat energy required to raise the energy temperature of 1 pound of water from 63 to 64ºF.

Table 3.10:

Physical Quantity	Name	Symbol	SI Unit
Force	Newton	N	$kg \bullet m/s^2$
Energy	Joule	J	$kg \bullet m^2/s^2$
Power	Watt	W	$kg \bullet m^2/s^3$

1 BRITISH THERMAL UNIT = 1055 JOULES

3.5 Matter and Organic Compounds

If you look at your hand, what do you see? Of course, you see skin, which consists of cells. But what are skin cells made of? Like all living cells, they are made of matter. In fact, all things are made of matter. **Matter** is anything that takes up space and has mass. Matter, in turn, is made up of chemical substances. In this lesson you will learn about the chemical substances that make up living things.

A chemical substance is matter that has a definite composition. It also has the same composition throughout. A chemical substance may be either an element or a compound.

An **element** is a pure substance. It cannot be broken down into other types of substances. Each element is made up of just one type of atom. An atom is the smallest particle of an element that still has the properties of that element.

There are almost 120 known elements. As you can see from **Figure** 3.1, the majority of elements are metals. Examples of metals are iron (Fe) and copper (Cu). Metals are shiny and good conductors of electricity and heat. Nonmetal elements are far fewer in number. They include hydrogen (H) and oxygen (O). They lack the properties of metals.

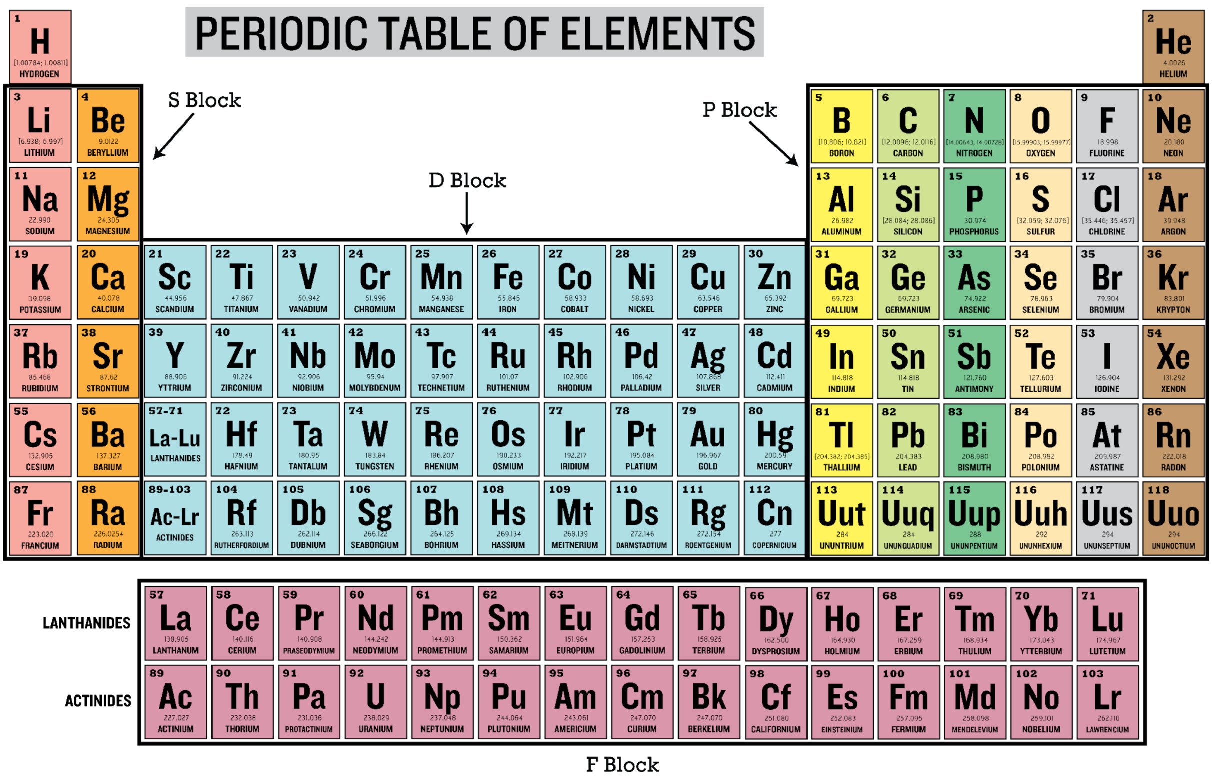


Figure 3.1: Periodic Table of the Elements. The Periodic Table of the Elements arranges elements in groups based on their properties. The element most important to life is carbon (C). Find carbon in the table. What type of element is it, metal or nonmetal?

A **compound** is a substance that consists of two or more elements. A compound has a unique composition that is always the same. The smallest particle of a compound is called a molecule. Consider water as an example. A molecule of water always contains one atom of oxygen and two atoms of hydrogen. The composition of water is expressed by the chemical formula H_2O. A model of a water molecule is shown in **Figure** 3.2.

What causes the atoms of a water molecule to “stick” together? The answer is chemical bonds. A

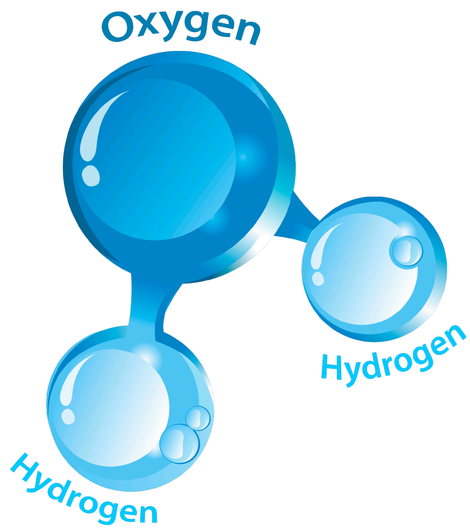


Figure 3.2: Water Molecule. A water molecule always has this composition, one atom of oxygen and two atoms of hydrogen.

chemical bond is a force that holds molecules together. Chemical bonds form when substances react with one another. A **chemical reaction** is a process that changes some chemical substances into others. A chemical reaction is needed to form a compound. Another chemical reaction is needed to separate the substances in a compound.

The Significance of Carbon

A compound found mainly in living things is known as an **organic compound**. Organic compounds make up the cells and other structures of organisms and carry out life processes. Carbon is the main element in organic compounds, so carbon is essential to life on Earth. Without carbon, life as we know it could not exist. Why is carbon so basic to life? The reason is carbon's ability to form stable bonds with many elements, including itself. This property allows carbon to form a huge variety of very large and complex molecules. In fact, there are nearly 10 million carbon-based compounds in living things! However, the millions of organic compounds can be grouped into just four major types: carbohydrates, lipids, proteins, and nucleic acids. You can compare the four types in **Table** 3.11. Each type is also described below.

Table 3.11: **Types of Organic Compounds**

Type of Compound	Examples	Elements	Functions
Carbohydrates	sugars, starches	carbon, hydrogen, oxygen	provides energy to cells, stores energy, forms body structures
Lipids	fats, oils	carbon, hydrogen, oxygen	stores energy, forms cell membranes, carries messages
Proteins	enzymes, antibodies	carbon, hydrogen, oxygen, nitrogen, sulfur	helps cells keep their shape, makes up muscles, speeds up chemical reactions, carries messages and materials

Table 3.11: (continued)

Type of Compound	Examples	Elements	Functions
Nucleic Acids	DNA, RNA	carbon, hydrogen, oxygen, nitrogen, phosphorus	contains instructions for proteins, passes instructions from parents to offspring, helps make proteins

The Miracle of Life: Carbohydrates, Proteins, Lipids & Nucleic Acids video can be viewed at

http://www.youtube.com/watch?v=nMevuu0Hxuc (3:28).

1. **Carbohydrates**: Carbohydrates are the most common type of organic compound. A carbohydrate is an organic compound such as sugar or starch, and is used to store energy. Like most organic compounds, carbohydrates are built of small, repeating units that form bonds with each other to make a larger molecule. In the case of carbohydrates, the small repeating units are called monosaccharides.
2. **Lipids:** A lipid is an organic compound such as fat or oil. Organisms use lipids to store energy, but lipids have other important roles as well. Lipids consist of repeating units called fatty acids. There are two types of fatty acids: saturated fatty acids and unsaturated fatty acids.
3. **Proteins:** A protein is an organic compound made up of small molecules called **amino acids**. There are 20 different amino acids commonly found in the proteins of living things. Small proteins may contain just a few hundred amino acids, whereas large proteins may contain thousands of amino acids.
4. **Nucleic Acid:** A nucleic acid is an organic compound, such as DNA or RNA, that is built of small units called **nucleotides**. Many nucleotides bind together to form a chain called a **polynucleotide**. The nucleic acid **DNA** (deoxyribonucleic acid) consists of two polynucleotide chains. The nucleic acid **RNA** (ribonucleic acid) consists of just one polynucleotide chain.

Functions of Proteins

Proteins play many important roles in living things. Some proteins help cells keep their shape, and some make up muscle tissues. Many proteins speed up chemical reactions in cells. Other proteins are antibodies, which bind to foreign substances such as bacteria and target them for destruction. Still other proteins carry messages or materials. For example, human red blood cells contain a protein called hemoglobin, which binds with oxygen. Hemoglobin allows the blood to carry oxygen from the lungs to cells throughout the body. A model of the hemoglobin molecule is shown in **Figure** 3.3.

A short video describing protein function can be viewed at http://www.youtube.com/watch?v=T500B5yTy58&#

(4:02).

An overview of DNA can be seen at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/4/

-vZ_g7K6P0 (28:05).

The binding of complementary bases allows DNA molecules to take their well-known shape, called a **double helix**, which is shown in **Figure** 3.5. A double helix is like a spiral staircase. The double helix shape forms

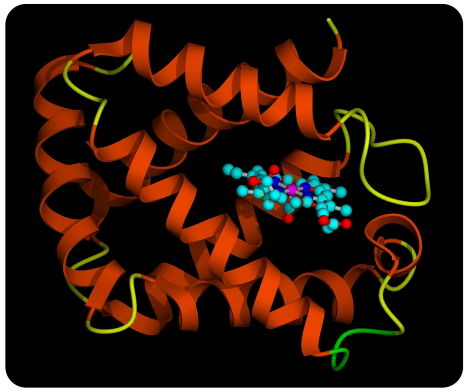


Figure 3.3: Hemoglobin Molecule. This model represents the protein hemoglobin. The red parts of the molecule contain iron. The iron binds with oxygen molecules.

Figure 3.4: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/101

naturally and is very strong, making the two polynucleotide chains difficult to break apart. The structure of DNA will be further discussed in the chapter *Molecular Genetics: From DNA to Proteins.*

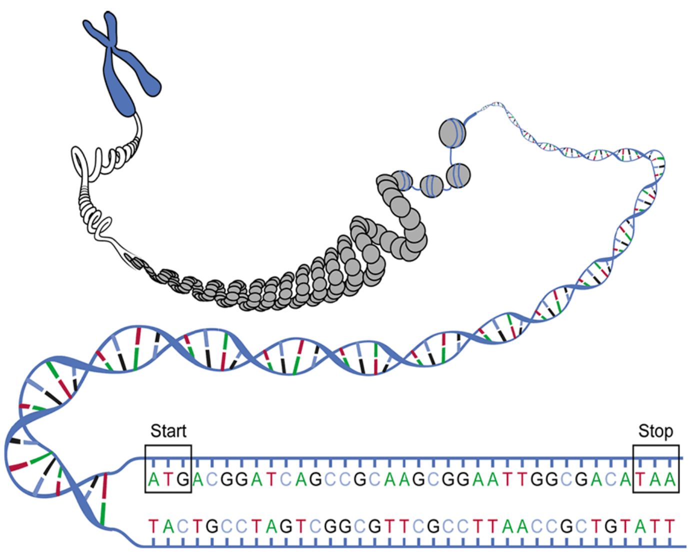


Figure 3.5: DNA Molecule. Bonds between complementary bases help form the double helix of a DNA molecule. The letters A, T, G, and C stand for the bases adenine, thymine, guanine, and cytosine. The sequence of these four bases in DNA is a code that carries instructions for making proteins. The start and stop codons are shown; these will be discussed in the Molecular Genetics: From DNA to Proteins chapter.

An animation of DNA structure can be viewed at http://www.youtube.com/watch?v=qy8dk5iS1f0&feature=

Roles of Nucleic Acids

DNA is found in genes, and its sequence of bases makes up a code. Between "starts" and "stops," the code carries instructions for the correct sequence of amino acids in a protein (see **Figure** 3.5). RNA uses the information in DNA to assemble the correct amino acids and help make the protein. The information in DNA is passed from parent cells to daughter cells whenever cells divide. The information in DNA is also passed from parents to offspring when organisms reproduce. This is how inherited characteristics are passed from one generation to the next.

3.6 Biochemical Reactions

What Are Chemical Reactions?

A chemical reaction is a process that changes some chemical substances into others. A substance that starts a chemical reaction is called a **reactant**, and a substance that forms as a result of a chemical reaction is called a **product**. During a chemical reaction, the reactants are used up to create the products.

An example of a chemical reaction is the burning of methane, which is shown in **Figure** 3.6. In this chemical reaction, the reactants are methane (CH_4) and oxygen (O_2), and the products are carbon dioxide (CO_2) and water (H_2O). A chemical reaction involves the breaking and forming of chemical bonds. When methane burns, bonds break in the methane and oxygen molecules, and new bonds form in the molecules of carbon dioxide and water.

Figure 3.6: Methane Burning. When methane burns, it combines with oxygen. What are the products of this chemical reaction?

Chemical Equations

A chemical reaction can be represented by a chemical equation. For example, the burning of methane can be represented by the chemical equation

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

The arrow in a chemical equation separates the reactants from the products and shows the direction in which the reaction proceeds. If the reaction could occur in the opposite direction as well, two arrows pointing in opposite directions would be used. The number 2 in front of O_2 and H_2O shows that two oxygen molecules and two water molecules are involved in the reaction. (With no number in front of a chemical symbol, just one molecule is involved.)

Conservation of Matter & Chemical Reactions

In a chemical reaction, the quantity of each element does not change; there is the same amount of each element in the products as there was in the reactants. This is because matter is always conserved. The conservation of matter is reflected in a reaction's chemical equation. The same number of atoms of each element appears on each side of the arrow. For example, in the chemical equation above, there are four hydrogen atoms on each side of the arrow. Can you find all four of them on each side of this equation?

Chemical reactions always involve energy. When methane burns, for example, it releases energy in the form of heat and light. Other chemical reactions absorb energy rather than release it.

Exothermic Reactions

A chemical reaction that releases energy (as heat) is called an **exothermic reaction**. This type of reaction can be represented by a general chemical equation:

Reactants $\rightarrow$ Products + Heat

In addition to methane burning, another example of an exothermic reaction is chlorine combining with sodium to form table salt. This reaction also releases energy.

Endothermic Reactions

A chemical reaction that absorbs energy is called an **endothermic reaction**. This type of reaction can also be represented by a general chemical equation:

Reactants + Heat $\rightarrow$ Products

Did you ever use a chemical cold pack like the one in **Figure** 3.7? The pack cools down because of an endothermic reaction. When a tube inside the pack is broken, it releases a chemical that reacts with water inside the pack. This reaction absorbs heat energy and quickly cools down the pack.

Figure 3.7: This pack gets cold due to an endothermic reaction.

Activation Energy

All chemical reactions need energy to get started. Even reactions that release energy need a boost of energy in order to begin. The energy needed to start a chemical reaction is called **activation energy**. Activation energy is like the push a child needs to start going down a playground slide. The push gives the child enough energy to start moving, but once she starts, she keeps moving without being pushed again. Activation energy is illustrated in **Figure** 3.8.

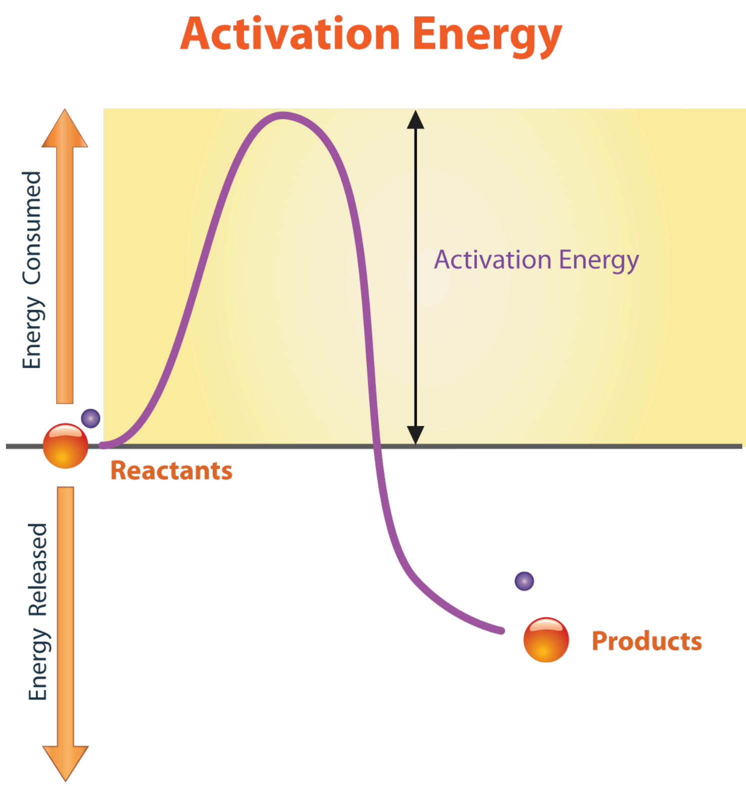


Figure 3.8: Activation Energy. Activation energy provides the

Why do all chemical reactions need energy to get started? In order for reactions to begin, reactant molecules must bump into each other, so they must be moving, and movement requires energy. When reactant molecules bump together, they may repel each other because of intermolecular forces pushing them apart. Overcoming these forces so the molecules can come together and react also takes energy.


An overview of activation energy can be viewed at http://www.youtube.com/watch?v=VbIaK6PLrRM&fea (1:16).

Biochemical reactions are chemical reactions that take place inside the cells of living things. The field of biochemistry demonstrates that knowledge of chemistry as well as biology is needed to understand fully the life processes of organisms at the level of the cell. The sum of all the biochemical reactions in an organism is called **metabolism**. It includes both exothermic and endothermic reactions.

Types of Biochemical Reactions

Exothermic reactions in organisms are called **catabolic reactions**. These reactions break down molecules into smaller units and release energy. An example of a catabolic reaction is the breakdown of glucose, which releases energy that cells need to carry out life processes. Endothermic reactions in organisms are called **anabolic reactions**. These reactions build up bigger molecules from smaller ones. An example of an anabolic reaction is the joining of amino acids to form a protein. Which type of reactions—catabolic or anabolic—do you think occur when your body digests food?

Enzymes

Most biochemical reactions in organisms need help in order to take place. Why is this the case? For one thing, temperatures are usually too low inside living things for biochemical reactions to occur quickly enough to maintain life. The concentrations of reactants may also be too low for them to come together and react. Where do the biochemical reactions get the help they need to proceed? The help comes from enzymes.

An **enzyme** is a protein that speeds up a biochemical reaction. An enzyme works by reducing the amount of activation energy needed to start the reaction. The graph in **Figure** 3.9 shows the activation energy needed for glucose to combine with oxygen. Less activation energy is needed when the correct enzyme is present than when it is not present. You can watch an animation of a biochemical reaction with and without an enzyme at the link below.

This animation shows how the enzyme brings reactant molecules together so they can react: http://www.stolaf.ed orien.swf.

An overview of enzymes can be viewed at http://www.youtube.com/watch?v=E90D4BmaVJM&feature=re (9:43).

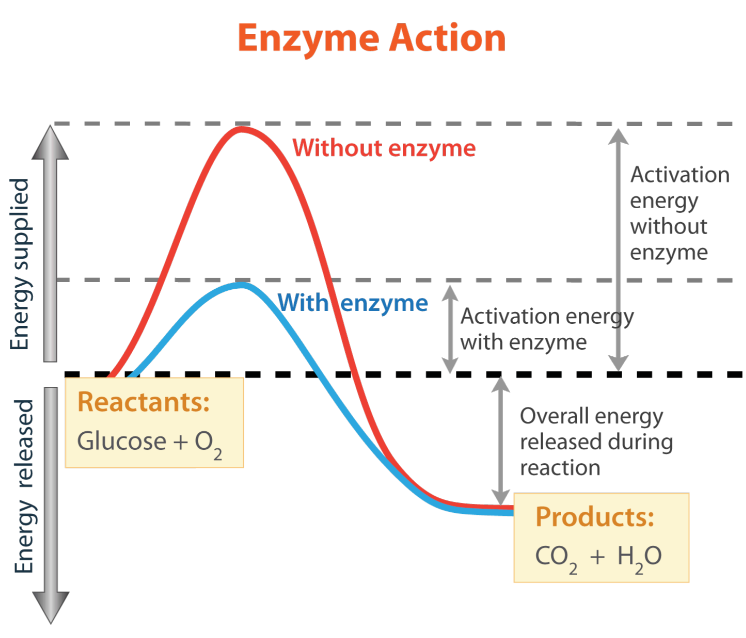


Figure 3.9: Enzyme Action. This graph shows what happens when glucose combines with oxygen. An enzyme speeds up the reaction by lowering the activation energy. Compare the activation energy needed with and without the enzyme.

Enzymes are involved in most biochemical reactions, and they do their job extremely well. A typical biochemical reaction could take several days to occur without an enzyme. With the proper enzyme, the same reaction can occur in just a split second! Without enzymes to speed up biochemical reactions, most organisms could not survive. The activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.


An animation of how enzymes work can be seen at http://www.youtube.com/watch?v=CZD5xsOKres&featu

(2:02).

3.7 Water, Acids, and Bases

Water, Water Everywhere

Water, like carbon, has a special role in living things. It is needed by all known forms of life. As you have seen, water is a simple molecule, containing just three atoms. Nonetheless, water's structure gives it unique properties that help explain why it is vital to all living organisms.

Water is a common chemical substance on planet Earth. In fact, Earth is sometimes called the "water planet" because almost 75% of its surface is covered with water. If you look at **Figure** 3.10, you will see where Earth's water is found. The term *water* generally refers to its liquid state, and water is a liquid over a wide range of temperatures on Earth. However, water also occurs on Earth as a solid (ice) and as a gas (water vapor).

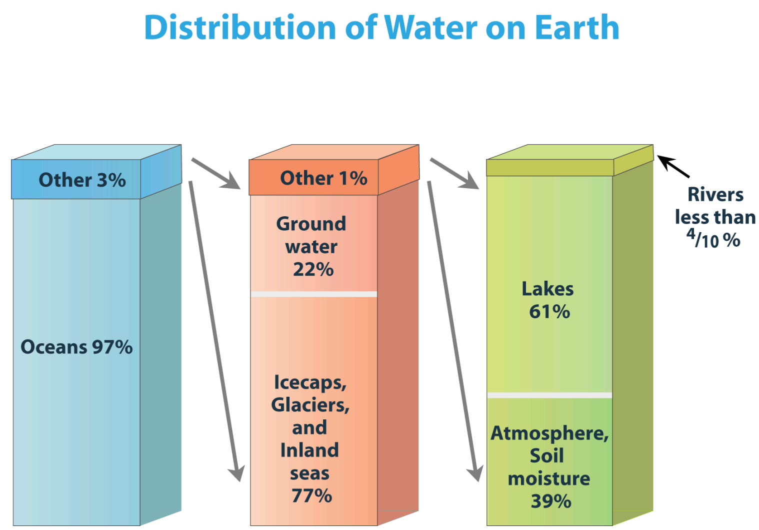


Figure 3.10: Most of the water on Earth consists of saltwater in the oceans. What percent of Earth

Structure and Properties of Water

No doubt, you are already aware of some of the properties of water. For example, you probably know that water is tasteless and odorless. You also probably know that water is transparent, which means that light can pass through it. This is important for organisms that live in the water, because some of them need sunlight to make food.

Chemical Structure of Water

To understand some of water's properties, you need to know more about its chemical structure. As you have seen, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge. A difference in electrical charge between different parts of the same molecule is called **polarity**. The diagram in **Figure** 3.11 shows water's polarity.

Opposites attract when it comes to charged molecules. In the case of water, the positive (hydrogen) end of one water molecule is attracted to the negative (oxygen) end of a nearby water molecule. Because of

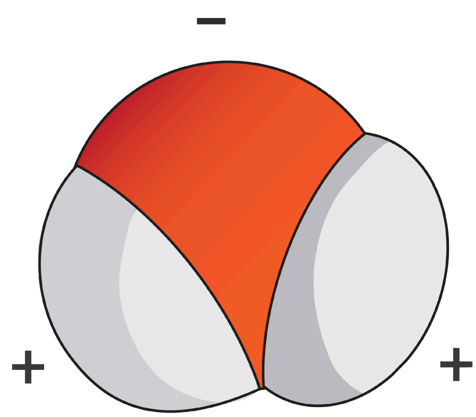


Figure 3.11: Water Molecule. This diagram shows the positive and negative parts of a water molecule.

this attraction, weak bonds form between adjacent water molecules, as shown in **Figure** 3.12. The type of bond that forms between molecules is called a **hydrogen bond**. Bonds between molecules are not as strong as bonds within molecules, but in water they are strong enough to hold together nearby molecules.

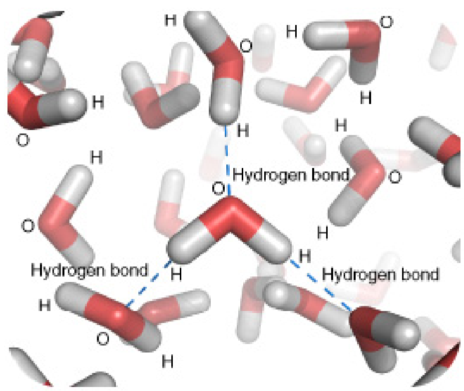


Figure 3.12: Hydrogen Bonding in Water Molecules. Hydrogen bonds form between nearby water molecules. How do you think this might affect water

Properties of Water

Hydrogen bonds between water molecules explain some of water's properties. For example, hydrogen bonds explain why water molecules tend to stick together. Did you ever watch water drip from a leaky faucet or from a melting icicle? If you did, then you know that water always falls in drops rather than as separate molecules. The dew drops in **Figure** 3.13 are another example of water molecules sticking together.

Hydrogen bonds cause water to have a relatively high boiling point of 100°C (212°F). Because of its high boiling point, most water on Earth is in a liquid state rather than in a gaseous state. Water in its liquid state is needed by all living things. Hydrogen bonds also cause water to expand when it freezes. This, in turn, causes ice to have a lower density (mass/volume) than liquid water. The lower density of ice means that it floats on water. For example, in cold climates, ice floats on top of the water in lakes. This allows lake animals such as fish to survive the winter by staying in the water under the ice.

Figure 3.13: Droplets of Dew. Drops of dew cling to a spider web in this picture. Can you think of other examples of water forming drops? (Hint: What happens when rain falls on a newly waxed car?)

Acids and Bases

Water is the main ingredient of many solutions. A **solution** is a mixture of two or more substances that has the same composition throughout. Some solutions are acids and some are bases. To understand acids and bases, you need to know more about pure water. In pure water (such as distilled water), a tiny fraction of water molecules naturally breaks down to form ions. An ion is an electrically charged atom or molecule. The breakdown of water is represented by the chemical equation

$2\ H_2O \rightarrow H_3O^+ + OH^-$

The products of this reaction are a hydronium ion (H_3O^+) and a hydroxide ion (OH^-). The hydroxide ion, which has a negative charge, forms when a water molecule gives up a positively charged hydrogen ion (H^+). The hydronium ion, which has positive charge, forms when another water molecule accepts the hydrogen ion.

Acidity and pH

The concentration of hydronium ions in a solution is known as acidity. In pure water, the concentration of hydronium ions is very low; only about 1 in 10 million water molecules naturally breaks down to form a hydronium ion. As a result, pure water is essentially neutral. Acidity is measured on a scale called **pH**, as shown in **Figure** 3.14. Pure water has a pH of 7, so the point of neutrality on the pH scale is 7.

Acids

If a solution has a higher concentration of hydronium ions than pure water, it has a pH lower than 7. A solution with a pH lower than 7 is called an **acid**. As the hydronium ion concentration increases, the pH value decreases. Therefore, the more acidic a solution is, the lower its pH value is. Did you ever taste vinegar? Like other acids, it tastes sour. Stronger acids can be harmful to organisms. For example, stomach acid would eat through the stomach if it were not lined with a layer of mucus. Strong acids can also damage materials, even hard materials such as glass.

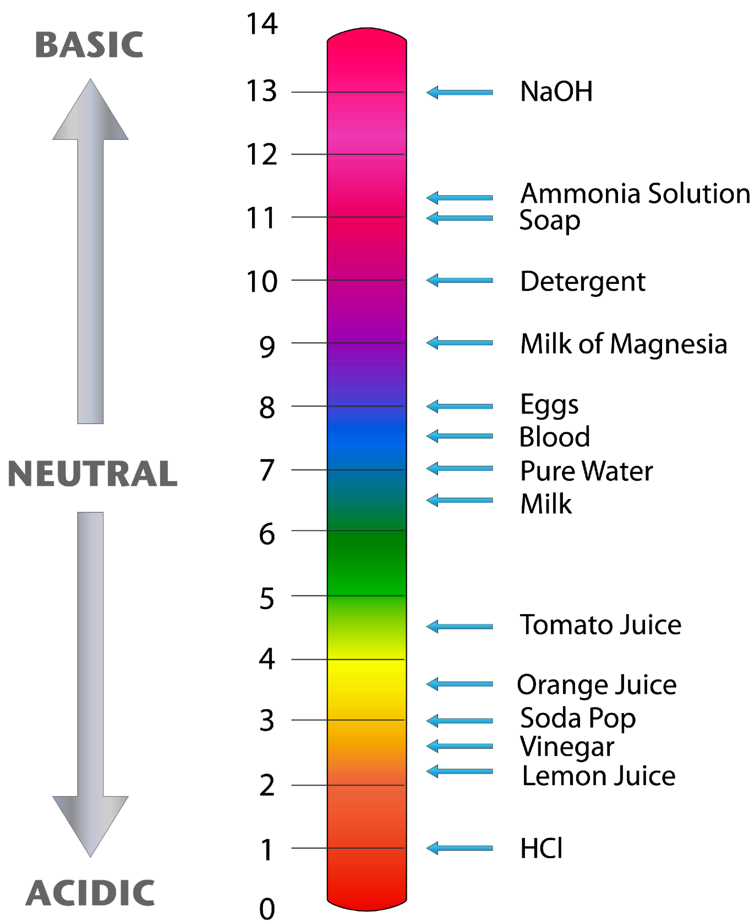


Figure 3.14: pH Scale. The pH scale ranges from 0 to 14, with 7 being the point of neutrality. What is the pH of lemon juice? Of milk?

Bases

If a solution has a lower concentration of hydronium ions than pure water, it has a pH higher than 7. A solution with a pH higher than 7 is called a **base**. Bases, such as baking soda, have a bitter taste. Like strong acids, strong bases can harm organisms and damage materials. For example, lye can burn the skin, and bleach can remove the color from clothing.

Acids and Bases in Organisms

Acids and bases are important in living things because most enzymes can do their job only at a certain level of acidity. Cells secrete acids and bases to maintain the proper pH for enzymes to work. For example, every time you digest food, acids and bases are at work in your digestive system. Consider the enzyme pepsin, which helps break down proteins in the stomach. Pepsin needs an acidic environment to do its job, and the stomach secretes a strong acid that allows pepsin to work. However, when stomach contents enter the small intestine, the acid must be neutralized. This is because enzymes in the small intestine need a basic environment in order to work. An organ called the pancreas secretes a strong base into the small intestine, and this base neutralizes the acid.

Water and Life

The human body is about 70% water (not counting the water in body fat, which varies from person to person). The body needs all this water to function normally. Just why is so much water required by human beings and other organisms? Water can dissolve many substances that organisms need, and it is necessary for many biochemical reactions. The examples below are among the most important biochemical processes that occur in living things, but they are just two of many ways that water is involved in biochemical reactions.

- Photosynthesis—In this process, cells use the energy in sunlight to change carbon dioxide and water to glucose and oxygen. The reactions of photosynthesis can be represented by the chemical equation

$6CO_2 + 6H_2O + \text{Energy} \rightarrow C_6H_{12}O_6 + 6O_2$

- Cellular respiration—In this process, cells break down glucose in the presence of oxygen and release carbon dioxide, water, and energy. The reactions of cellular respiration can be represented by the chemical equation

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

Water is involved in many other biochemical reactions. As a result, just about all life processes depend on water. Clearly, life as we know it could not exist without water.

3.8 End of Chapter Review & Resources

Chapter Summary

Living things consist of matter, which can be an element or a compound. A compound consists of two or more elements and forms as a result of a chemical reaction.Carbon's unique ability to form chemical bonds allows it to form millions of different large, organic compounds. These compounds make up living things and carry out life processes. Carbohydrates are organic compounds such as sugars and starches. They provide energy and form structures such as cell walls. Lipids are organic compounds such as fats and oils. They store energy and help form cell membranes in addition to having other functions in organisms. Proteins are organic compounds made up of amino acids. They form muscles, speed up chemical reactions, and perform many other cellular functions. Nucleic acids are organic compounds that include DNA and RNA. DNA contains genetic instructions for proteins, and RNA helps assemble the proteins. A chemical reaction is a process that changes some chemical substances into others. It involves breaking and forming chemical bonds. Some chemical reactions release energy, whereas other chemical reactions absorb energy. All chemical reactions require activation energy to get started. Enzymes are needed to speed up biochemical reactions in organisms. They work by lowering activation energy. Most of Earth's water is salt water in the oceans. Less than 3% is freshwater. Water molecules are polar, so they form hydrogen bonds. This gives water unique properties, such as a relatively high boiling point. The extremely low hydronium ion concentration of pure water gives pure water a neutral pH of 7. Acids have a pH lower than 7, and bases have a pH higher than 7. Water is involved in most biochemical reactions. Therefore, water is essential to life.

Review Questions

1. Usually, a course in environmental science begins with a discussion about energy and not biology. Why is energy so important?
2. Name the various types of energy and give examples of each.
3. Identify an energy source and sink.
4. What are elements and compounds? Give an example of each.
5. List the four major types of organic compounds.
6. State two functions of proteins.
7. Assume that you are trying to identify an unknown organic molecule. It contains only carbon, hydrogen, and oxygen and is found in the cell walls of a newly discovered plant species. What type of organic compound is it?
8. Explain why carbon is essential to all known life on Earth.
9. Identify the roles of reactants and products in chemical reactions.
10. What is the general chemical equation for an endothermic reaction?
11. What are biochemical reactions? What is an example?
12. How do enzymes speed up biochemical reactions?
13. What is wrong with the chemical equation below? How could you fix it? (hint: remember that all chemical equations should have the same number of elements on either side). $CH_4 + O_2 \rightarrow CO_2 + 2H_2O$
14. How does a chemical equation show that matter is always conserved in a chemical reaction?
15. Why do all chemical reactions require activation energy?
16. What type of reaction (endothermic or exothermic) is represented by the following chemical equation? Explain your answer. $2Na + 2HCl \rightarrow 2NaCl + H_2 + \text{heat}$
17. Explain why organisms need enzymes to survive.
18. What are the special characteristics of water that make it so vital to life on Earth?

19. Where is most of Earth's water found?
20. What is polarity? Describe the polarity of water.
21. What is the pH of a neutral solution?
22. Describe an example of an acid or a base that is involved in human digestion.
23. Assume that you test an unknown solution and find that it has a pH of 7.2. What type of solution is it? How do you know?
24. How could you demonstrate to a child that solid water is less dense than liquid water?
25. Explain how water's polarity is related to its boiling point.
26. Explain why metabolism (cellular respiration) in organisms depends on water.

Further Reading / Supplemental Links

- James D. Watson, *The Double Helix: A Personal Account of the Discovery of DNA*. Touchstone, 2001.
- The Chemistry of Biology http://www.infoplease.com/cig/biology/organic-chemistry.html

Vocabulary to Know

- activation energy
- acid
- amino acid
- anabolic reaction
- base
- biochemical reaction
- carbohydrate
- catabolic reaction
- chemical bond
- chemical reaction
- compound
- double helix
- element
- endothermic reaction
- enzyme
- exothermic reaction
- hydrogen bond
- lipid
- matter
- metabolism
- nucleic acid
- nucleotide
- organic compound
- pH
- polarity
- polynucleotide
- product
- protein
- reactant
- RNA
- solution

Credits

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For **Table ??**, from top to bottom:

- United States Department of Agriculture. http://commons.wikimedia.org/wiki/File:Potatoes.jpg. Public Domain.
- KGH. http://commons.wikimedia.org/wiki/File:Hepatocellular_carcinoma_histopathology_%282%29_-at_higher_magnification.jpg. CC-BY-SA 3.0.
- Image copyright Jubal Harshaw, 2011. http://www.shutterstock.com. Used under license from Shutterstock.com.
- Hafiz Issadeen. http://www.flickr.com/photos/yimhafiz/2547531809/. CC-BY 2.0.

Chapter 4

Biogeochemical Cycles and Recycling Matter

4.1 Introduction

Nutrient cycles are important ecosystem processes that release matter necessary for life back into the environment, and that help sustain natural processes. Human actions are now negatively affecting many of these cycles.

Chapter Objectives

- Describe the water cycle.
- Describe the carbon cycle.
- Understand how carbon regulates climate.
- Describe the nitrogen cycle.

- Describe the phosphorus cycle.

4.2 Recycling Matter

Unlike energy, elements are not lost and replaced as they pass through ecosystems. Instead, they are recycled repeatedly. All chemical elements that are needed by living things are recycled in ecosystems, including carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur. Water is also recycled.

Biogeochemical Cycles

A biogeochemical cycle is a closed loop through which a chemical element or water moves through ecosystems. In the term *biogeochemical, bio-* refers to biotic components and *geo-* to geological and other abiotic components. Chemicals cycle through both biotic and abiotic components of ecosystems. For example, an element might move from the atmosphere to ocean water, from ocean water to ocean organisms, and then back to the atmosphere to repeat the cycle.

Elements or water may be held for various lengths of time by different components of a biogeochemical cycle. Components that hold elements or water for a relatively short period of time are called exchange pools. For example, the atmosphere is an exchange pool for water. It holds water for several days at the longest. This is a very short time compared with the thousands of years the deep ocean can hold water. The ocean is an example of a reservoir for water. Reservoirs are components of a geochemical cycle that hold elements or water for a relatively long period of time.

Water Cycle

Earth's water is constantly in motion. Although the water on Earth is billions of years old, individual water molecules are always moving through the water cycle. The **water cycle** describes the continuous movement of water molecules on, above, and below Earth's surface. It is shown in **Figure** 4.1. Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating. During the cycle, water occurs in its three different states: gas (water vapor), liquid (water), and solid (ice). Processes involved in changes of state in the water cycle include evaporation, sublimation, and transpiration.

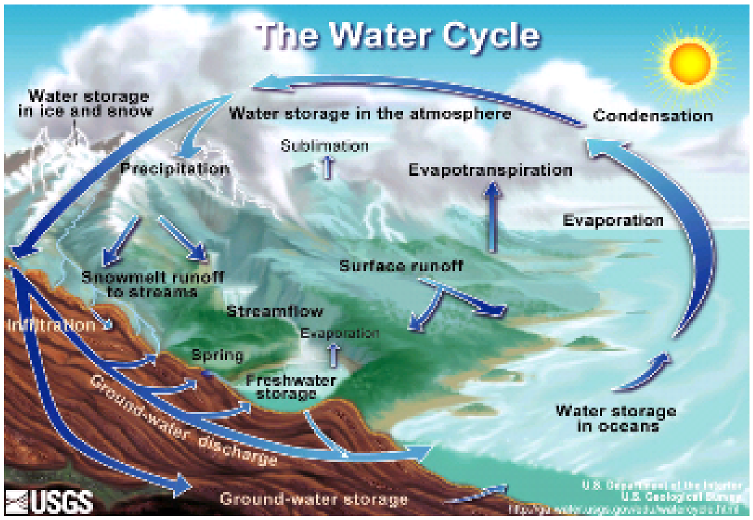

Figure 4.1: This diagram of the water cycle shows where water is stored and the processes by which water moves through the cycle, including evaporation, condensation, and precipitation.

The water cycle is demonstrated at http://www.youtube.com/watch?v=iohKd5FWZOE&feature=related (4:00).

Figure 4.2: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/167

Evaporation, Sublimation, and Transpiration

The sun is the driving force behind the water cycle. It heats oceans, lakes, and other bodies of water, causing water to evaporate from the surface and enter the atmosphere as water vapor. Water in soil also evaporates easily. In addition, the sun heats ice and snow, causing it to turn directly into water vapor in the process of **sublimation**. Water also evaporates from the above-ground parts of plants. Transpiration is another process by which plants lose water. **Transpiration** occurs when stomata in leaves open to take in carbon dioxide for photosynthesis and lose water to the atmosphere in the process.

The water cycle plays an important role in climate. For molecules of liquid water to change to water vapor, kinetic energy is required, or the energy of movement. As faster-moving molecules evaporate, the remaining molecules have lower average kinetic energy, and the temperature of ocean water thus decreases. The primary way that oceans slow global warming is by heat uptake which warms ocean water and removes some energy from the atmosphere.

Condensation and Precipitation

Rising air currents carry water vapor from all these sources into the atmosphere. As the water vapor rises higher into the atmosphere or is carried toward the poles by winds, the air becomes cooler. Cooler air cannot hold as much water vapor, so the water vapor condenses into tiny water droplets around particles in the air. The tiny water droplets form clouds.

Air currents cause the tiny water droplets in clouds to collide and merge into larger droplets. When water droplets in clouds become large enough to fall, they become **precipitation**. Most precipitation falls back into the ocean. Precipitation that falls at high altitudes or near the poles can accumulate as ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Infiltration and Runoff

Rain that falls on land may either soak into the ground, which is called **infiltration**, or flow over the land as **runoff**. Snow that falls on land eventually melts, with the exception of snow that accumulates at high altitudes or near the poles. Like rain water, snowmelt can either infiltrate the ground or run off.

Water that infiltrates the ground is called **groundwater**. Groundwater close to the surface can be taken up by plants. Alternatively, it may flow out of the ground as a spring or slowly seep from the ground into bodies of water such as ponds, lakes, or the ocean. Groundwater can also flow deeper underground. It may eventually reach an aquifer. An **aquifer** is an underground layer of water-bearing, permeable rock. Groundwater may be stored in an aquifer for thousands of years. Wells drilled into an aquifer can tap this underground water and pump it to the surface for human use.

Runoff water from rain or snowmelt eventually flows into streams and rivers. The water is then carried to ponds, lakes, or the ocean. From these bodies of water, water molecules can evaporate to form water vapor and continue the cycle.

Carbon Cycle

Runoff, streams, and rivers can gradually dissolve carbon in rocks and carry it to the ocean. The ocean is a major reservoir for stored carbon. It is just one of four major reservoirs. The other three are the atmosphere, the biosphere, and organic sediments such as fossil fuels. Fossil fuels, including petroleum and coal, form from the remains of dead organisms. All of these reservoirs of carbon are interconnected by pathways of exchange in the carbon cycle, which is shown in **Figure** 4.3.

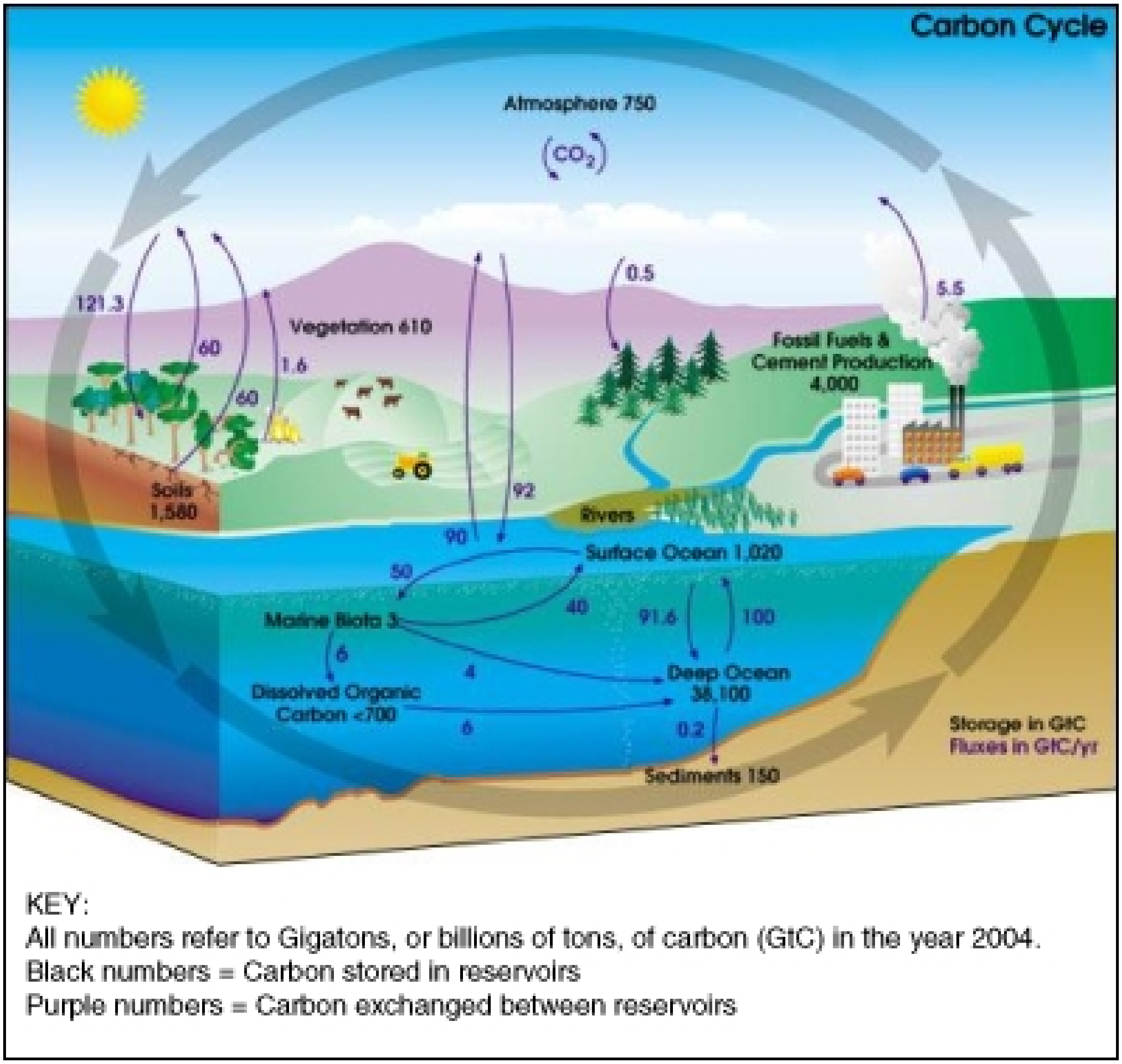

Figure 4.3: This drawing of the carbon cycle shows the amounts of carbon stored in and exchanged between carbon reservoirs on land and in water. Another 70 million GtC of carbon may be stored in sedimentary rock. If this is true, it would make sedimentary rock the greatest reservoir of carbon on Earth.

Carbon occurs in a various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in **Table** 4.1. Refer to the table as you read how carbon moves between reservoirs of the cycle.

Table 4.1: **Forms of Carbon in the Carbon Cycle: Carbon Dioxide, Gas, Calcium Carbonate, Solids**

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3	Liquid(dissolvedion)	Ocean
Organic Compounds	*Examples:* Glucose, $C_6H_{12}O_6$ Methane, CH_4	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)
Other Carbon Compounds	*Examples:* Calcium Carbonate, $CaCO_3$ Calcium Magnesium Carbonate, $CaMg(CO_3)_2$	Solid Solid	Sedimentary Rock, Shells Sedimentary Rock

KEY: C = Carbon, O = Oxygen, H = Hydrogen

Carbon in the Atmosphere

In the atmosphere, carbon exists primarily as carbon dioxide (CO_2). Carbon dioxide enters the atmosphere from several different sources, including those listed below. Most of the sources are also represented in **Figure 2,** and some are described in detail later in the lesson.

- Living organisms release carbon dioxide as a byproduct of cellular respiration.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.

A much smaller amount of carbon in the atmosphere is present as methane gas (CH_4). Methane is released into the atmosphere when dead organisms and other organic matter decay in the absence of oxygen. It is produced by landfills, the mining of fossil fuels, and some types of agriculture.

There are also several different ways that carbon leaves the atmosphere. Carbon dioxide is removed from the atmosphere when plants and other autotrophs take in carbon dioxide to make organic compounds during photosynthesis or chemosynthesis. Carbon dioxide is also removed when ocean water cools and dissolves more carbon dioxide from the air. These processes are also represented in **Figure** 4.3.

Because of human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years. Burning fossil fuels and producing concrete has released great quantities of carbon dioxide into the atmosphere. Cutting forests and clearing land has also increased carbon dioxide into the atmosphere because these activities reduce the number of autotrophic organisms that use up carbon dioxide in photosynthesis. In addition, clearing often involves burning, which releases carbon dioxide that was previously stored in autotrophs.

The carbon cycle (**6d**) is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8 (1:56).

Figure 4.4: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/169

Carbon in Ocean Water

Most carbon enters the ocean when carbon dioxide in the atmosphere dissolves in ocean water. When carbon dioxide dissolves in water (H_2O), it forms an acid called carbonic acid (H_2CO_3). The reaction is given by the equation:

$CO_2 + H_2O \leftrightarrow H_2CO_3$.

The double-headed arrow indicates that the reaction can occur in either direction, depending on the conditions and the amount of carbon dioxide present. For example, the reaction occurs more readily in the left-to-right direction in cold water. As a result, near the poles, where ocean water is cooler, more carbon dioxide is dissolved and there is more carbonic acid in the water. Although carbonic acid is a weak acid, it is an important regulator of the acid-base (pH) balance of ocean water.

Carbonic acid, in turn, readily separates into hydrogen ions (H^+) and bicarbonate ions (HCO_3). This occurs in the following reaction:

$H_2CO_3 \leftrightarrow H^+ + HCO_3$.

Due to these two reactions, most dissolved carbon dioxide in the ocean is in the form of bicarbonate ions. Another source of bicarbonate ions in ocean water is runoff. Flowing water erodes rocks containing carbon compounds such as calcium carbonate. This forms bicarbonate ions, which the runoff carries to streams, rivers, and eventually the ocean. Many of the bicarbonate ions in ocean water are moved by ocean currents into the deep ocean. Carbon can be held in this deep ocean reservoir as bicarbonate ions for thousands of years or more.

Carbon in the Biosphere

Bicarbonate ions near the surface of the ocean may be taken up by photosynthetic algae and bacteria that live near the surface. These and other autotrophic organisms use bicarbonate ions or other forms of carbon to synthesize organic compounds. Carbon is essential for life because it is the main ingredient of every type of organic compound. Organic compounds make up the cells and tissues of all organisms and keep organisms alive and functioning. Carbon enters all ecosystems, both terrestrial and aquatic, through autotrophs such as plants or algae. Autotrophs use carbon dioxide from the air, or bicarbonate ions from the water, to make organic compounds such as glucose. Heterotrophs consume the organic molecules and pass the carbon through food chains and webs.

How does carbon cycle back to the atmosphere or ocean? All organisms release carbon dioxide as a byproduct of cellular respiration. Recall from the *Cellular Respiration* chapter that **cellular respiration** is the process by which cells oxidize glucose and produce carbon dioxide, water, and energy. Decomposers also release carbon dioxide when they break down dead organisms and other organic waste.

In a balanced ecosystem, the amount of carbon used in photosynthesis and passed through the ecosystem is about the same as the amount given off in respiration and decomposition. This cycling of carbon between the atmosphere and organisms forms an organic pathway in the carbon cycle. Carbon can cycle quickly through this organic pathway, especially in aquatic ecosystems. In fact, during a given period of time, much more carbon is recycled through the organic pathway than through the geological pathway you will read about next.

Carbon in Rocks and Sediments

The geological pathway of the carbon cycle takes much longer than the organic pathway described above. In fact, it usually takes millions of years for carbon to cycle through the geological pathway. It involves processes such as rock formation, subduction, and volcanism.

As stated previously, most carbon in ocean water is in the form of bicarbonate ions. Bicarbonate ions may bind with other ions, such as calcium ions (Ca^+) or magnesium ions (Mg^+), and form insoluble compounds. Because the compounds are insoluble, they precipitate out of water and gradually form sedimentary rock, such as limestone (calcium carbonate, $CaCO_3$) or dolomite [calcium magnesium carbonate $CaMg(CO_3)_2$.

Dead organisms also settle to the bottom of the ocean. Many of them have shells containing calcium carbonate. Over millions of years, the pressure of additional layers of sediments gradually changes their calcium carbonate and other remaining organic compounds to carbon-containing sedimentary rock.

During some periods in Earth's history, very rich organic sediments were deposited. These deposits formed pockets of hydrocarbons. Hydrocarbons are organic compounds that contain only carbon and hydrogen. The hydrocarbons found in sediments are fossil fuels such as natural gas. The hydrocarbon methane is the chief component of natural gas.

Carbon-containing rocks and sediments on the ocean floor gradually move toward the edges of the ocean due to a process called seafloor spreading. The rocks eventually reach cracks in the crust, where they are pulled down into the mantle. This process, called **subduction**, occurs at subduction zones. In the mantle, the rocks melt and their carbon is stored. When volcanoes erupt, they return some of the stored carbon in the mantle to the atmosphere in the form of carbon dioxide, a process known as **volcanism**. This brings the geological pathway of the carbon cycle full circle.

Nitrogen Cycle

The atmosphere is the largest reservoir of nitrogen on Earth. It consists of 78 percent nitrogen gas (N_2). The **nitrogen cycle** moves nitrogen through abiotic and biotic components of ecosystems. **Figure** 4.5 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes from the atmosphere into soil. Then it moves through several different organisms before returning to the atmosphere to complete the cycle. In aquatic ecosystems, nitrogen passes through a similar cycle.

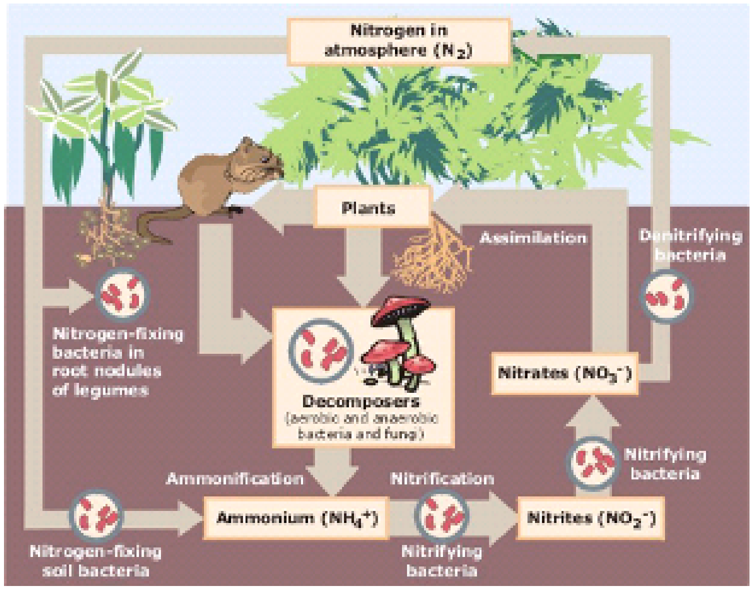

Figure 4.5: In a terrestrial ecosystem, the nitrogen cycle may include plants and consumers as well as several types of bacteria.

The nitrogen cycle (**6d**) is discussed at http://www.youtube.com/watch?v=pdY4I-EaqJA&feature=fvw (5:08).

Figure 4.6: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/170

Absorption of Nitrogen

Plants and other producers use nitrogen to synthesize nitrogen-containing organic compounds. These include chlorophyll, proteins, and nucleic acids. Other organisms that consume producers make use of the nitrogen in these organic compounds. Plants absorb substances such as nitrogen from the soil through their root hairs. However, they cannot absorb nitrogen gas directly. They can absorb nitrogen only in the form of nitrogen-containing ions, such as nitrate ions (NO_3).

Nitrogen Fixation

The process of converting nitrogen gas to nitrate ions that plants can absorb is called **nitrogen fixation**. It is carried out mainly by nitrogen-fixing bacteria, which secrete enzymes needed for the process. Some nitrogen-fixing bacteria live in soil. Others live in the root nodules of legumes such as peas and beans. In aquatic ecosystems, some cyanobacteria are nitrogen fixing. They convert nitrogen gas to nitrate ions that algae and other aquatic producers can use.

Nitrogen gas in the atmosphere can be converted to nitrates by several other means. One way is by the energy in lightning. Nitrogen is also converted to nitrates as a result of certain human activities. These include the production of fertilizers and explosives and the burning of fossil fuels. These human activities also create the gas nitrous oxide (N_2O). The concentration of this gas in the atmosphere has tripled over the past hundred years as a result. Nitrous oxide is a greenhouse gas that contributes to global warming and other environmental problems.

Ammonification and Nitrification

After being used by plants and animals, nitrogen is released back into the environment. When decomposers break down organic remains and wastes, they release nitrogen in the form of ammonium ions (NH_4). This is called **ammonification**. It occurs in both terrestrial and aquatic ecosystems. In terrestrial ecosystems, some nitrogen-fixing bacteria in soil and root nodules also convert nitrogen gas directly into ammonium ions.

Although some plants can absorb nitrogen in the form of ammonium ions, others cannot. In fact, ammonium ions may be toxic to some plants and other organisms. Certain soil bacteria, called nitrifying bacteria, convert ammonium ions to nitrites (NO_2). Other nitrifying bacteria convert the nitrites to nitrates, which plants can absorb. The process of converting ammonium ions to nitrites or nitrates is called **nitrification**.

Denitrification and the Anammox Reaction

Still other bacteria, called denitrifying bacteria, convert some of the nitrates in soil back into nitrogen gas in a process called **denitrification**. The process is the opposite of nitrogen fixation. Denitrification returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.

In the ocean, another reaction occurs to cycle nitrogen back to nitrogen gas in the atmosphere. The reaction, called the **anammox reaction**, is enabled by certain bacteria in the water. In the reaction, ammonium and nitrite ions combine to form water and nitrogen gas. This is shown by the equation:

$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$.

The anammox reaction may contribute up to half of the nitrogen gas released into the atmosphere by the ocean. The reaction may also significantly limit production in ocean ecosystems by removing nitrogen compounds that are needed by aquatic producers and other organisms.

4.3 End of Chapter Review & Resources

Chapter Summary

Matter cycles are important means of putting nutrients back into ecosystems. Biogeochemical cycles are closed loops through which chemical elements or water move through ecosystems. Examples of biogeochemical cycles include the water cycle, carbon cycle, and nitrogen cycle. The water cycle recycles water through ecosystems. Processes by which water changes state in the water cycle include evaporation, sublimation, transpiration, and condensation. The organic pathway of the carbon cycle moves carbon from the atmosphere, through producers and other organisms in ecosystems, and back to the atmosphere. The geological pathway moves carbon from the atmosphere, through the ocean to rocks and the mantle, and back to the atmosphere. The nitrogen cycle moves nitrogen gas from the atmosphere into soil or water, where nitrogen-fixing bacteria convert it to a form that producers can use. Nitrifying bacteria help nitrogen cycle through ecosystems. Denitrifying bacteria return nitrogen gas back to the atmosphere. The anammox reaction returns nitrogen back to the atmosphere from ocean water.

Review Questions

1. What abiotic factors might be involved in recycling matter? For example, what abiotic factors might be involved in recycling water?
2. What is a biogeochemical cycle? Name one example.
3. Identify and define two processes by which water changes state in the water cycle.
4. State three ways that carbon dioxide enters Earth's atmosphere.
5. How do bacteria convert nitrogen gas to a form that producers can use?
6. Describe all the ways that a single tree might be involved in the carbon cycle.
7. Explain why growing a crop of legumes can improve the ability of the soil to support the growth of other plants.
8. Compare and contrast organic and geological pathways in the carbon cycle.
9. Identify an exchange pool and a reservoir in the water cycle. Explain your choices.
10. Matter is recycled through abiotic and biotic components of all ecosystems. However, ecosystems vary in the amount of matter they recycle. For example, forests recycle more matter than deserts.
    (a) What factors do you think might cause ecosystems to differ in this way?
    (b) What abiotic components of the environment do you think might be important?
    (c) What about the amount of sunlight or precipitation that ecosystems receive?
    (d) What roles do you think these abiotic components play in cycles of matter?

Further Reading / Supplemental Links

- http://earthobservatory.nasa.gov/Library/CarbonCycle/
- http://estrellamountain.edu/faculty/farabee/biobk/BioBookcycles.html
- http://estrellamountain.edu/faculty/farabee/biobk/BioBookcommecosys.html
- http://estrellamountain.edu/faculty/farabee/biobk/BioBookpopecol.html http://estrellamountain.edu/faculty/
- http://earthobservatory.nasa.gov/Library/CarbonCycle/
- http://ide.ucsd.edu/earthguide/diagrams/watercycle/
- http://observe.arc.nasa.gov/nasa/earth/hydrocycle/hydro1.html

Vocabulary to Know

- ammonification - The release of nitrogen in the form of ammonium ions (NH_4) due to the break down of organic remains and wastes by decomposers.
- anammox reaction - Reaction in which ammonium and nitrite ions combine to form water and nitrogen gas; enabled by certain bacteria in the water.
- aquifer - An underground layer of water-bearing, permeable rock.
- biogeochemical cycle - A closed loop through which a chemical element or water moves through ecosystems.
- carbon cycle - Pathways of exchange that interconnect the four major reservoirs of carbon: the ocean, the atmosphere, the biosphere and organic sediments, such as fossil fuels.
- denitrification - The conversion of some of the nitrates in soil back into nitrogen gas; done by denitrifying bacteria; returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.
- groundwater - Water that infiltrates the ground.
- infiltration - Rain that falls on land and soaks into the ground.
- nitrification - The process of converting ammonium ions to nitrites or nitrates.
- nitrogen cycle - The cycle that moves nitrogen through abiotic and biotic components of ecosystems.
- nitrogen fixation - The process of converting nitrogen gas to nitrate ions that plants can absorb; carried out mainly by nitrogen-fixing bacteria.
- precipitation - Forms when water droplets in clouds become large enough to fall.
- runoff - Rain that falls on land and flows over the land.
- subduction - A process where carbon containing rocks and sediments on the ocean floor are pulled down into the mantle; due to seafloor spreading.
- sublimation - The transformation of snow and ice directly into water vapor; occurs as the snow and ice are heated by the sun.
- transpiration - A process by which plants lose water; occurs when stomata in leaves open to take in carbon dioxide for photosynthesis and lose water to the atmosphere in the process.
- volcanism - The process of returning some of the stored carbon in the mantle to the atmosphere in the form of carbon dioxide; occurs when volcanoes erupt.
- water cycle - Describes the continuous movement of water molecules on, above, and below Earth's surface.

Credits

Chapter 5

Evolution of Species and Ecosystems

5.1 Introduction

The Grand Canyon, shown here, is an American icon and one of the wonders of the natural world. It's also a record of the past. Look at the rock layers in the picture. If you were to walk down a trail to the bottom of the canyon, with each step down you would be taking a step back in time. That's because lower layers of rock represent the more distant past. The rock layers and the fossils they contain show the history of Earth and its organisms over a 2-billion-year time span. Although Charles Darwin never visited the Grand Canyon, he saw rock layers and fossils in other parts of the world. They were one inspiration for his theory of evolution. Darwin's theory rocked the scientific world. In this chapter, you will read why.

Chapter Objectives

- State Darwin's theory of evolution by natural selection.
- Describe observations Darwin made on the voyage of the *Beagle.*
- Identify influences on Darwin's development of evolutionary theory.
- Explain how a species can evolve through natural selection.
- Describe how fossils help us understand the past.
- Explain how evidence from living species gives clues about evolution.
- State how biogeography relates to evolutionary change.
- Distinguish between microevolution and macroevolution.
- Define gene pool, and explain how to calculate allele frequencies.
- State the Hardy-Weinberg theorem
- Identify the four forces of evolution.
- Describe two ways that new species may originate.
- Define coevolution, and give an example.
- Distinguish between gradualism and punctuated equilibrium

5.2 Darwin and the Theory of Evolution

The Englishman Charles Darwin is one of the most famous scientists who ever lived. His place in the history of science is well deserved. Darwin's theory of evolution represents a giant leap in human understanding. It explains and unifies all of biology.

Darwin's Theory at a Glance

Darwin's theory of evolution actually contains two major ideas:

1. Organisms change over time. Life on Earth has changed as descendants diverged from common ancestors in the past.
2. Evolution occurs by natural selection. Natural selection is the process in which living things with beneficial traits produce more offspring than others do. This results in changes in the traits of living things over time.

In Darwin's day, most people believed that all species were created at the same time and remained unchanged thereafter. They also believed that Earth was only 6,000 years old. Therefore, Darwin's ideas revolutionized biology. How did Darwin come up with these important ideas? It all started when he went on a voyage.

The Voyage of the *Beagle*

In 1831, when Darwin was just 22 years old, he set sail on a scientific expedition on a ship called the *HMS Beagle*. He was the naturalist on the voyage. As a naturalist, it was his job to observe and collect specimens of plants, animals, rocks, and fossils wherever the expedition went ashore. The route the ship took and the stops they made are shown in **Figure** 5.1. You can learn more about Darwin's voyage at this link: http://www.aboutdarwin.com/voyage/voyage03.html.

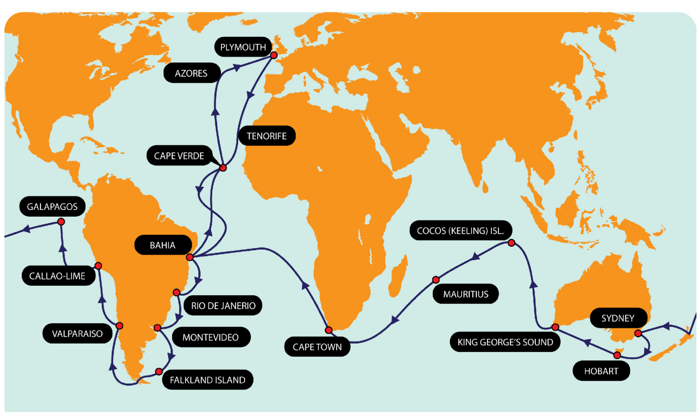

Figure 5.1: Voyage of the Beagle. This map shows the route of Darwin

Darwin was fascinated by nature, so he loved his job on the *Beagle.* He spent more than 3 years of the 5-year trip exploring nature on distant continents and islands. While he was away, a former teacher published Darwin's accounts of his observations. By the time Darwin finally returned to England, he had become famous as a naturalist.

Darwin's Observations

During the long voyage, Darwin made many observations that helped him form his theory of evolution. For example:

- He visited tropical rainforests and other new habitats where he saw many plants and animals he had never seen before (see **Figure** 5.2). This impressed him with the great diversity of life.
- He experienced an earthquake that lifted the ocean floor 2.7 meters (9 feet) above sea level. He also found rocks containing fossil sea shells in mountains high above sea level. These observations suggested that continents and oceans had changed dramatically over time and continue to change in dramatic ways.
- He visited rock ledges that had clearly once been beaches that had gradually built up over time. This suggested that slow, steady processes also change Earth's surface.
- He dug up fossils of gigantic extinct mammals, such as the ground sloth (see **Figure** 5.2). This was hard evidence that organisms looked very different in the past. It suggested that living things—like Earth's surface—change over time.

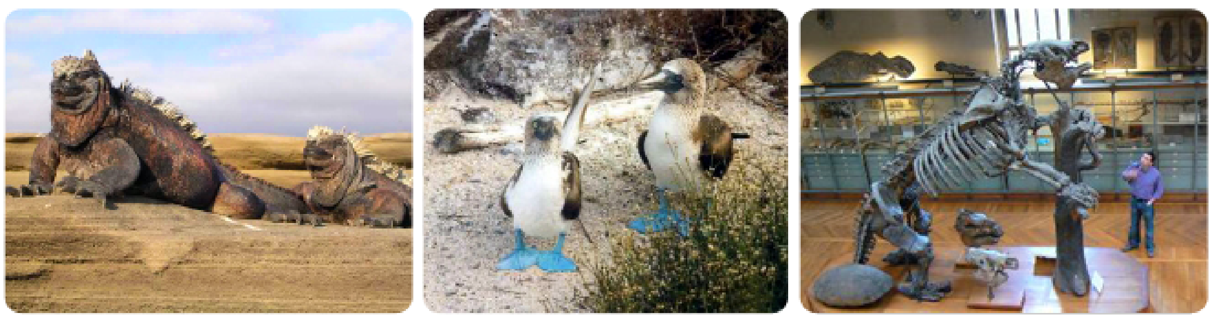

Figure 5.2: On his voyage, Darwin saw giant marine iguanas and blue-footed boobies. He also dug up the fossil skeleton of a giant ground sloth like the one shown here. From left: Giant Marine Iguana, Blue-Footed Boobies, and Fossil Skeleton of a Giant Ground Sloth

The Galápagos Islands

Darwin's most important observations were made on the **Galápagos Islands** (see map in **Figure** 5.3). This is a group of 16 small volcanic islands 966 kilometers (600 miles) off the west coast of South America.

Individual Galápagos islands differ from one another in important ways. Some are rocky and dry. Others have better soil and more rainfall. Darwin noticed that the plants and animals on the different islands also differed. For example, the giant tortoises on one island had saddle-shaped shells, while those on another island had dome-shaped shells (see **Figure** 5.4). People who lived on the islands could even tell the island a turtle came from by its shell. This started Darwin thinking about the origin of species. He wondered how each island came to have its own type of tortoise.

Influences on Darwin

Science, like evolution, always builds on the past. Darwin didn't develop his theory completely on his own. He was influenced by the ideas of earlier thinkers.

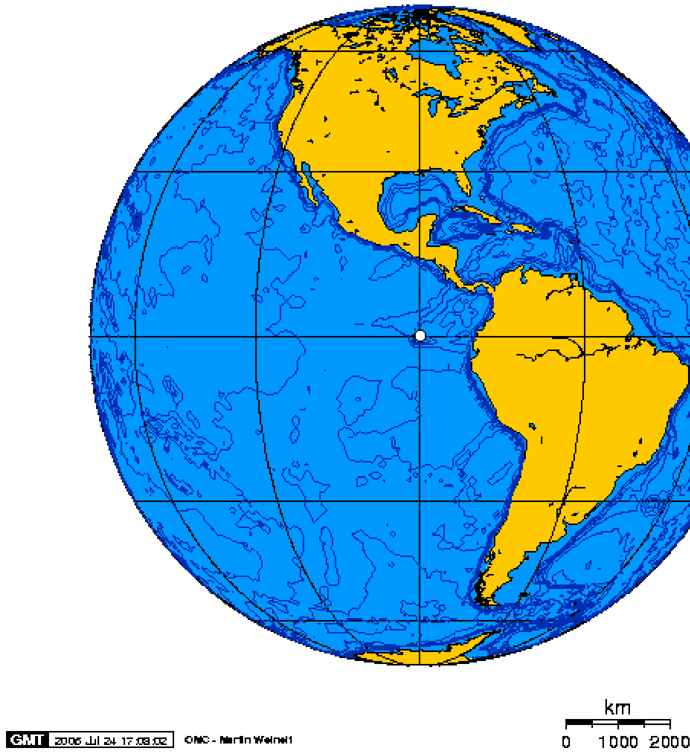

Figure 5.3: Gal

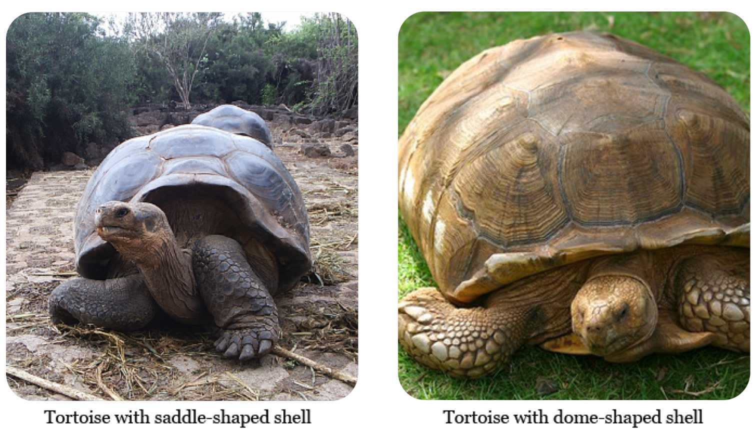

Figure 5.4: Gal

Earlier Thinkers Who Influenced Darwin

1. Jean Baptiste Lamarck (1744–1829) was an important French naturalist. He was one of the first scientists to propose that species change over time. However, Lamarck was wrong about how species change. His idea of the **inheritance of acquired characteristics** is incorrect. Traits an organism develops during its own life time cannot be passed on to offspring, as Lamarck believed.
2. Charles Lyell (1797–1875) was a well-known English geologist. Darwin took his book, *Principles of Geology,* with him on the *Beagle.* In the book, Lyell argued that gradual geological processes have gradually shaped Earth's surface. From this, Lyell inferred that Earth must be far older than most people believed.
3. Thomas Malthus (1766–1834) was an English economist. He wrote an essay titled *On Population.* In the essay, Malthus argued that human populations grow faster than the resources they depend on. When populations become too large, famine and disease break out. In the end, this keeps populations in check by killing off the weakest members.

Artificial Selection

The case of artificial selection also influenced Darwin. He was also aware that humans could breed plants and animals to have useful traits. By selecting which animals were allowed to reproduce, they could change an organism's traits. The pigeons in **Figure** 5.5 are good examples. Darwin called this type of change in organisms **artificial selection**. He used the word *artificial* to distinguish it from natural selection.

Wallace's Theory

Did you ever hear the saying that "great minds think alike?" It certainly applies to Charles Darwin and another English naturalist named Alfred Russel Wallace. Wallace lived at about the same time as Darwin. He also traveled to distant places to study nature. Wallace wasn't as famous as Darwin. However, he developed basically the same theory of evolution. While working in distant lands, Wallace sent Darwin a paper he had written. In the paper, Wallace explained his evolutionary theory. This served to confirm what Darwin already thought.

Applying Darwin's Theory

The following example applies Darwin's theory. It explains how giraffes came to have such long necks (see **Figure** 5.6).

- In the past, giraffes had short necks. But there was chance variation in neck length. Some giraffes had necks a little longer than the average.
- Then, as now, giraffes fed on tree leaves. Perhaps the environment changed, and leaves became scarcer. There would be more giraffes than the trees could support. Thus, there would be a "struggle for existence."
- Giraffes with longer necks had an advantage. They could reach leaves other giraffes could not. Therefore, the long-necked giraffes were more likely to survive and reproduce. They had greater fitness.
- These giraffes passed the long-neck trait to their offspring. Each generation, the population contained more long-necked giraffes. Eventually, all giraffes had long necks.

As this example shows, chance variations may help a species survive if the environment changes. Variation among species helps ensure that at least one will be able to survive environmental change.

Figure 5.5: Artificial Selection in Pigeons. Pigeon hobbyists breed pigeons to have certain characteristics. All three of the pigeons in the bottom row were bred from the common rock pigeon.

Figure 5.6: African Giraffes. Giraffes feed on leaves high in trees. Their long necks allow them to reach leaves that other ground animals cannot.

Norman Penny, collections manager of the entomology department of the California Academy of Sciences, gives QUEST viewers a peek at the California Academy of Sciences vast butterfly collection, and discusses the evolutionary importance of butterflies. See http://www.kqed.org/quest/television/cal-academy-butterfly-collection for additional information.

Figure 5.7: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/1390

The Farallon Islands: California's Galapagos

As one of 552 designated National Wildlife Refuges, the Farallon Islands are virtually uninhabited by humans. These islands are home to the largest seabird breeding colony in the contiguous United States. The Farallon Islands also have a rich diversity of marine life. They are the spawning grounds for numerous fish and invertebrate species, and at least 36 species of marine mammals have been observed in surrounding waters. This unique and fragile ecosystem has informally earned these islands the name *the Galapagos of California.*


Lying just 28 miles off the coast of California, the Farallon Islands sits amid one of the most productive marine food webs on the planet. http://www.kqed.org/quest/television/the-farallon-islands–californias-galapagos.

Figure 5.8: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/1530

5.3 Evidence for Evolution

For an excellent online resource on understanding evolution and its most important key points, see this link with The University of Berkeley: http://evolution.berkeley.edu/evolibrary/article/evo_01

In his book *On the Origin of Species,* Darwin included a lot of evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time, much more evidence has been gathered. The evidence includes a huge number of fossils. It also includes more detailed knowledge of living things, right down to their DNA.

Fossil Evidence

Fossils are a window into the past. They provide clear evidence that evolution has occurred. Scientists who find and study fossils are called **paleontologists**. How do they use fossils to understand the past? Consider the example of the horse, shown in **Figure** 5.9. The fossil record shows how the horse evolved.

The oldest horse fossils show what the earliest horses were like. They were about the size of a fox, and they had four long toes. Other evidence shows they lived in wooded marshlands, where they probably ate soft leaves. Through time, the climate became drier, and grasslands slowly replaced the marshes. Later fossils show that horses changed as well.

- They became taller, which would help them see predators while they fed in tall grasses.
- They evolved a single large toe that eventually became a hoof. This would help them run swiftly and escape predators.
- Their molars (back teeth) became longer and covered with cement. This would allow them to grind tough grasses and grass seeds without wearing out their teeth.

Similar fossil evidence demonstrates the evolution of the whale, moving from the land into the sea. An animation of this process can be viewed at http://collections.tepapa.govt.nz/exhibitions/whales/Segment.aspx?irn=161.

Does The Fossil Record Support Evolution? This video can be seen at http://www.youtube.com/watch?v=QWVoXZPC (9:20).

Evidence of Evolution from Living Species

Just as Darwin did, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

To learn more about homology and analogy, and the differences between them, check out this link at The University of Berkeley: http://evolution.berkeley.edu/evolibrary/article/similarity_hs_01

Homologous structures are structures that are similar in related organisms because they were inherited from a common ancestor. These structures may or may not have the same function in the descendants. **Figure** 5.10 shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.

Analogous structures are structures that are similar in unrelated organisms. The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in **Figure** 5.11, look similar on the outside. They also have

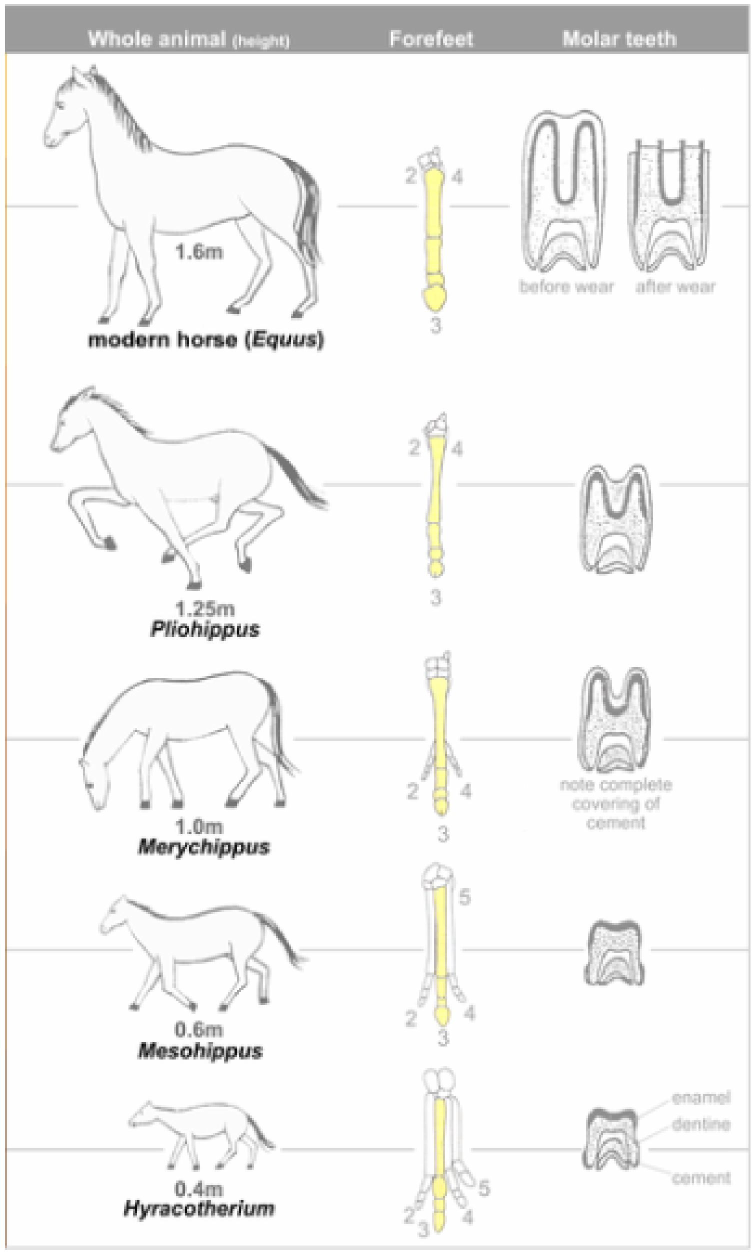

Figure 5.9: Evolution of the Horse. The fossil record reveals how horses evolved.

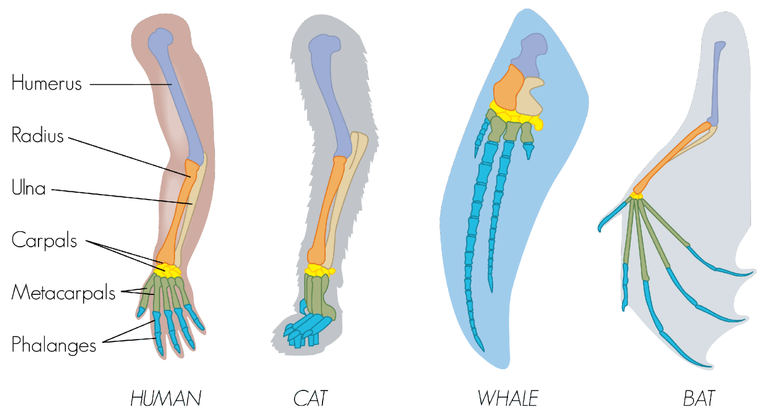

Figure 5.10: Hands of Different Mammals. The forelimbs of all mammals have the same basic bone structure.

the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.

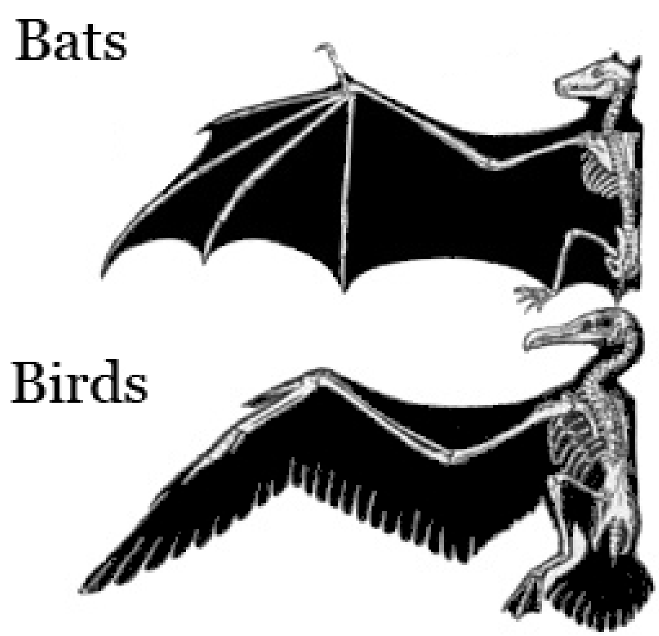

Figure 5.11: Wings of Bats and Birds. Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails, as shown in **Figure** 5.12. All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage.

Vestigial Structures are structures such as the human tailbone, or the small legs on snakes. Evolution

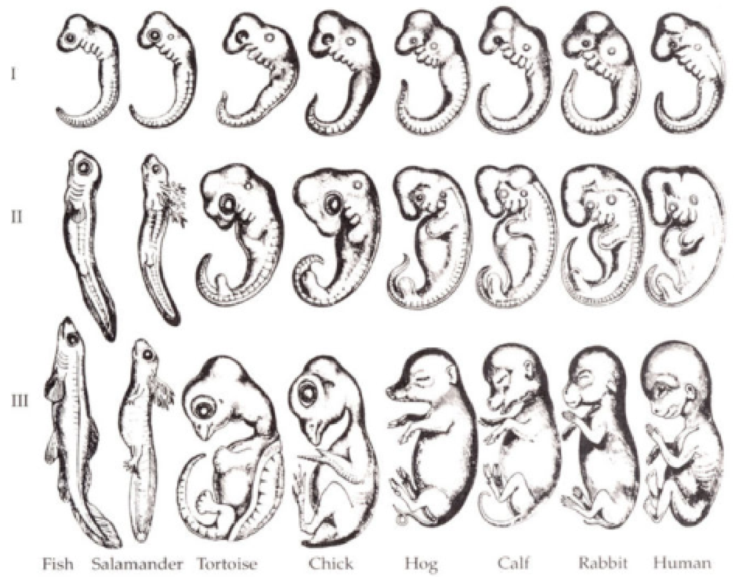

Figure 5.12: Vertebrate Embryos. Embryos of different vertebrates look much more similar than the adult organisms do.

has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?

Comparing DNA is also an important tool for studying evolution. Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in **Figure** 5.13. It shows how humans and apes are related based on their DNA sequences.

Evolution and molecules are discussed at http://www.youtube.com/watch?v=nvJFI3ChOUU (3:52).


Using various types of information to understand evolutionary relationships is discussed in the following videos:

1. http://www.youtube.com/watch?v=aZc1t2Os6UU (3:38)
2. http://www.youtube.com/watch?v=6IRz85QNjz0 (6:45)
3. http://www.youtube.com/watch?v=JgyTVT3dqGY&feature=related (10:51)

Evidence from Biogeography

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

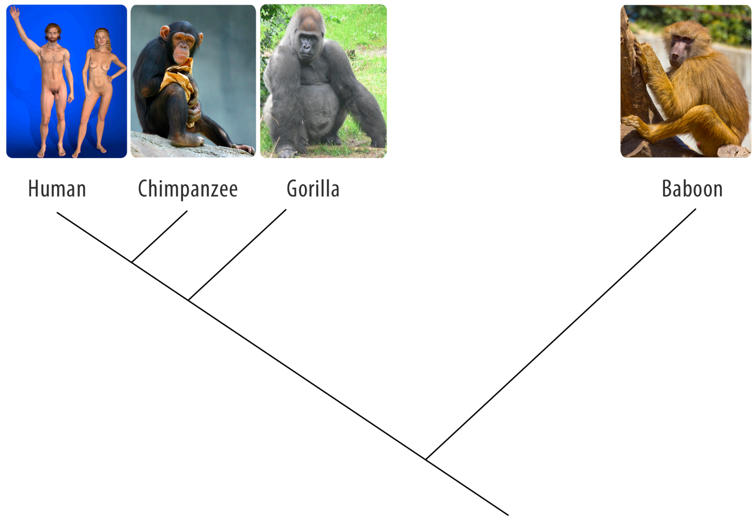

Figure 5.13: Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

Biogeography of Camels: An Example

Today, the camel family includes different types of camels. They are shown in **Figure** 5.14. All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.

Island Biogeography

The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (see **Figure** 5.15). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of **adaptive radiation**. This is the process by which a single species evolves into many new species to fill available niches.

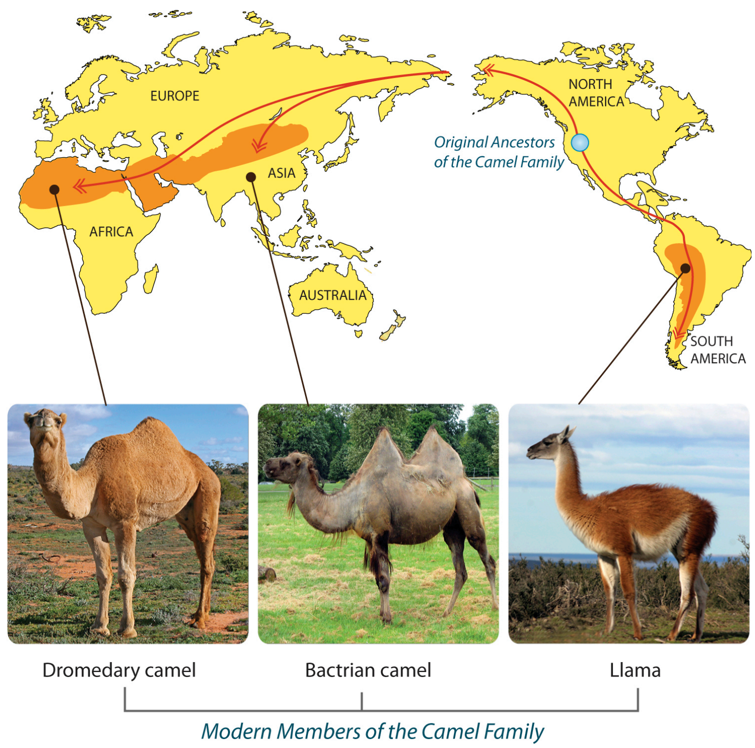

Figure 5.14: Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits. However, they share basic similarities. This is because they all evolved from a common ancestor. What differences and similarities do you see?

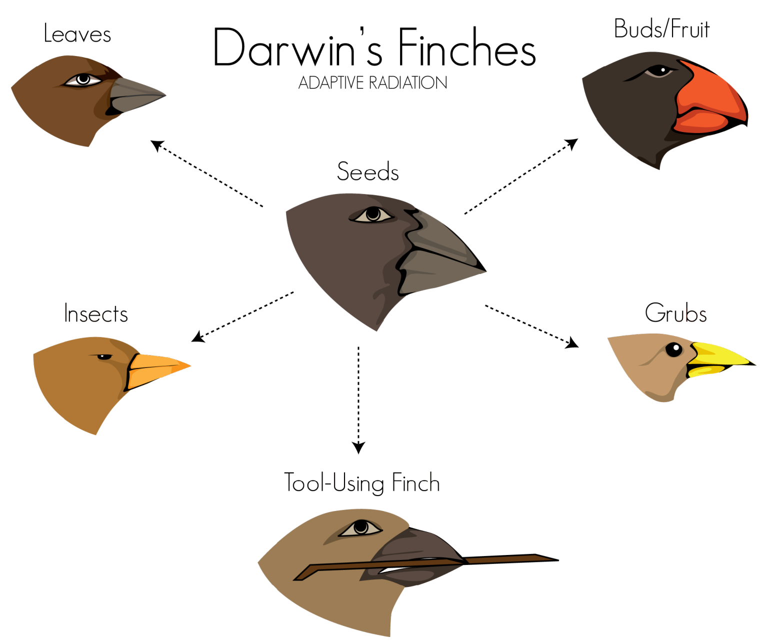

Figure 5.15: Gal

5.4 Case Study: Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place. While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (see **Figure** 5.16). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.

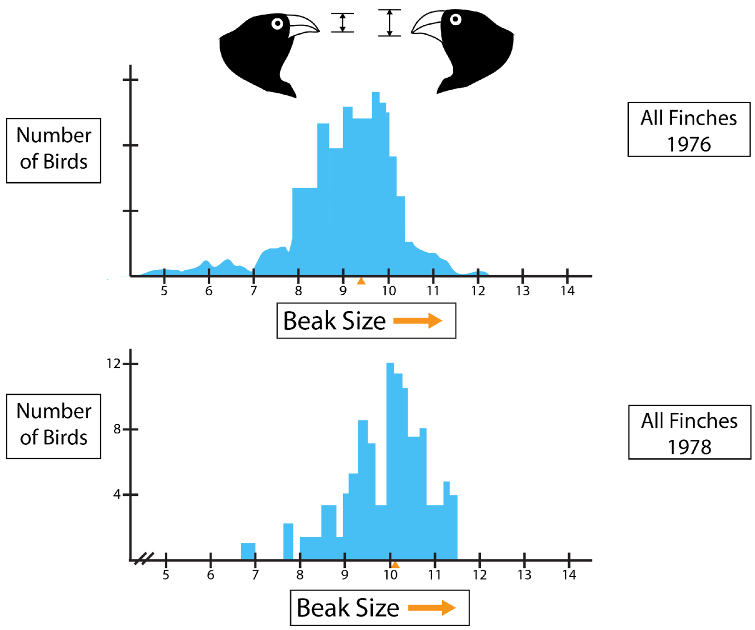

Figure 5.16: Evolution of Beak Size in Gal

5.5 Microevolution and the Genetics of Populations

Darwin knew that heritable variations are needed for evolution to occur. However, he knew nothing about Mendel's laws of genetics. Mendel's laws were rediscovered in the early 1900s. Only then could scientists fully understand the process of evolution.

The Scale of Evolution

We now know that variations of traits are heritable. These variations are determined by different alleles. We also know that evolution is due to a change in alleles over time. How long a time? That depends on the scale of evolution.

- **Microevolution** occurs over a relatively short period of time within a population or species. The Grants observed this level of evolution in Darwin's finches.
- **Macroevolution** occurs over geologic time above the level of the species. The fossil record reflects this level of evolution. It results from microevolution taking place over many generations.

Genes in Populations

Individuals do not evolve. Their genes do not change over time. The unit of evolution is the population. A population consists of organisms of the same species that live in the same area. In terms of evolution, the population is assumed to be a relatively closed group. This means that most mating takes place within the population. The science that focuses on evolution within populations is **population genetics**. It is a combination of evolutionary theory and Mendelian genetics.

The genetic makeup of an individual is the individual's genotype. A population consists of many genotypes. Altogether, they make up the population's gene pool. The **gene pool** consists of all the genes of all the members of the population. For each gene, the gene pool includes all the different alleles for the gene that exist in the population. For a given gene, the population is characterized by the frequency of the different alleles in the gene pool.

Allele frequency is how often an allele occurs in a gene pool relative to the other alleles for that gene. Look at the example in **Table ??**. The population in the table has 100 members. In a sexually reproducing species, each member of the population has two copies of each gene. Therefore, the total number of copies of each gene in the gene pool is 200. The gene in the example exists in the gene pool in two forms, alleles A and a. Knowing the genotypes of each population member, we can count the number of alleles of each type in the gene pool. The table shows how this is done. Evolution occurs in a population when allele frequencies change over time. What causes allele frequencies to change? That question was answered by Godfrey Hardy and Wilhelm Weinberg in 1908.

The Hardy-Weinberg Theorem

Hardy was an English mathematician. Weinberg was a German doctor. Each worked alone to come up with the founding principle of population genetics. Today, that principle is called the **Hardy-Weinberg theorem**. It shows that allele frequencies do not change in a population if certain conditions are met. Such a population is said to be in Hardy-Weinberg equilibrium. The conditions for equilibrium are:

1. No new mutations are occurring. Therefore, no new alleles are being created.

2. There is no migration. In other words, no one is moving into or out of the population.
3. The population is very large.
4. Mating is at random in the population. This means that individuals do not choose mates based on genotype.
5. There is no natural selection. Thus, all members of the population have an equal chance of reproducing and passing their genes to the next generation.

When all these conditions are met, allele frequencies stay the same.

Forces of Evolution

The conditions for Hardy-Weinberg equilibrium are unlikely to be met in real populations. The Hardy-Weinberg theorem also describes populations in which allele frequencies are not changing. By definition, such populations are not evolving. How does the theorem help us understand evolution in the real world?

From the theorem, we can infer factors that cause allele frequencies to change. These factors are the forces of evolution. There are four such forces: mutation, gene flow, genetic drift, and natural selection.

1. **Mutation :** creates new genetic variation in a gene pool. It is how all new alleles first arise. In sexually reproducing species, the mutations that matter for evolution are those that occur in gametes. Only these mutations can be passed to offspring. For any given gene, the chance of a mutation occurring in a given gamete is very low. Thus, mutations alone do not have much effect on allele frequencies. However, mutations provide the genetic variation needed for other forces of evolution to act.
2. **Gene flow** : occurs when individuals move into or out of a population. If the rate of migration is high, this can have a significant effect on allele frequencies. Both the population they leave and the population they enter may change. During the Vietnam War in the 1960s and 1970s, many American servicemen had children with Vietnamese women. Most of the servicemen returned to the United States after the war. However, they left copies of their genes behind in their offspring. In this way, they changed the allele frequencies in the Vietnamese gene pool. Was the gene pool of the American population also affected? Why or why not?
3. **Natural Selection** : occurs when there are differences in fitness among members of a population. As a result, some individuals pass more genes to the next generation. This causes allele frequencies to change.
4. **Genetic drift** : is a random change in allele frequencies that occurs in a small population. When a small number of parents produce just a few offspring, allele frequencies in the offspring may differ, by chance, from allele frequencies in the parents. This is like tossing a coin. If you toss a coin just a few times, you may, by chance, get more or less than the expected 50 percent heads or tails. In a small population, you may also, by chance, get different allele frequencies than expected in the next generation. In this way, allele frequencies may drift over time. There are two special conditions under which genetic drift occurs. They are called bottleneck effect and founder effect.
   (a) Bottleneck effect occurs when a population suddenly gets much smaller. This might happen because of a natural disaster such as a forest fire. By chance, allele frequencies of the survivors may be different from those of the original population.
   (b) Founder effect occurs when a few individuals start, or found, a new population. By chance, allele frequencies of the founders may be different from allele frequencies of the population they left. An example is described in **Figure** 5.17.

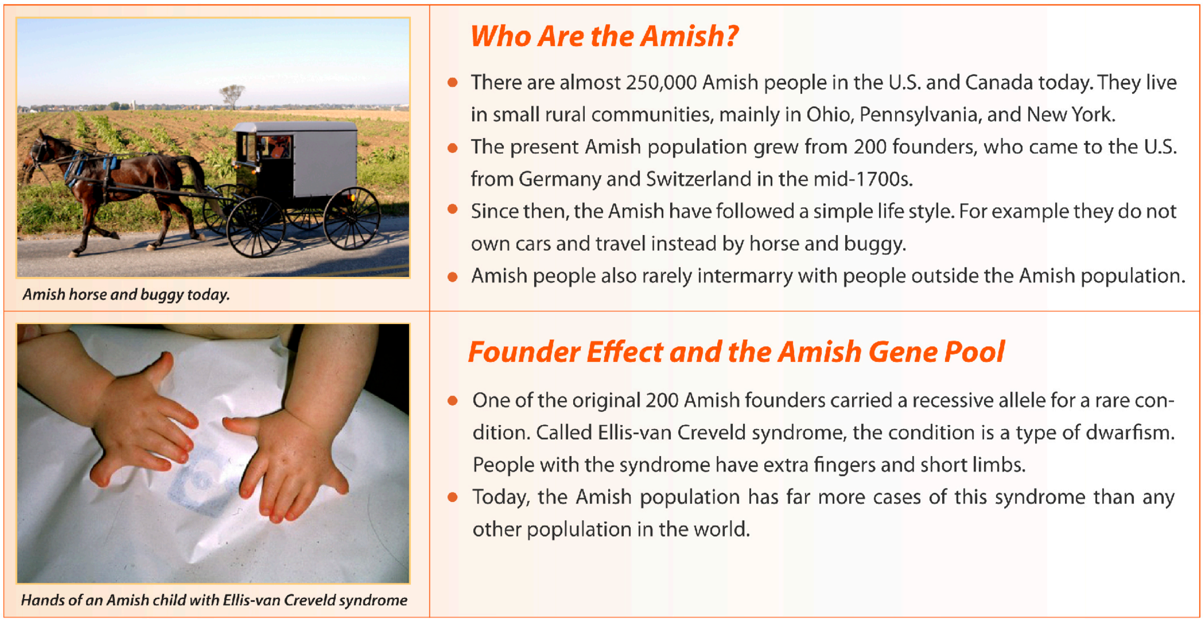

Figure 5.17: Founder Effect in the Amish Population. The Amish population in the U.S. and Canada had a small number of founders. How has this affected the Amish gene pool?

5.6 Macroevolution and the Origin of Species

Macroevolution is evolution over geologic time above the level of the species. One of the main topics in macroevolution is how new species arise. The process by which a new species evolves is called **speciation**. How does speciation occur? How does one species evolve into two or more new species?

Origin of Species

To understand how a new species forms, it's important to review what a species is. A species is a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? Usually they become geographically isolated first.

Allopatric Speciation

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species. Speciation that occurs in this way is called **allopatric speciation**. An example is described in **Figure** 5.18.

Sympatric Speciation

Less often, a new species arises without geographic separation. This is called **sympatric speciation**. The following example shows one way this can occur.

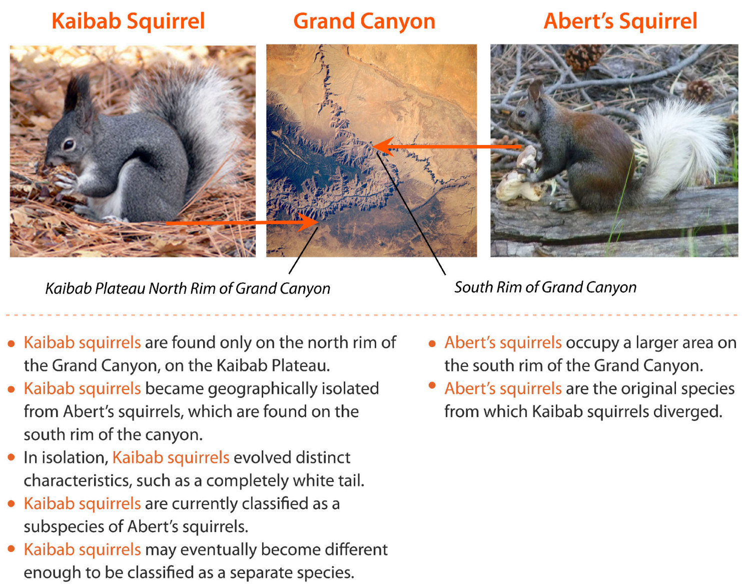

Figure 5.18: Allopatric Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

1. Hawthorn flies lay eggs in hawthorn trees (see **Figure** 5.19). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
2. Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
3. Over time, the two fly populations—those that fed on hawthorn trees and those that preferred apple trees—evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
4. Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

Hawthorn Fly | Hawthorn Berries | Apples

Figure 5.19: Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

Isolating mechanisms are discussed in the following video http://www.youtube.com/watch?v=-e64TfKeAXU (2:57).

Coevolution

Evolution occurs in response to a change in the environment. Environmental change often involves other species of organisms. In fact, species in symbiotic relationships tend to evolve together. This is called **coevolution**. As one species changes, the other species must also change in order to adapt.

Coevolution occurs in flowering plants and the species that pollinate them. The flower and bird in **Figure** 5.20 are a good example. They have evolved matching structures.

Figure 5.20: Results of Coevolution in a Flower and Its Pollinator. The very long mouth part of this hummingbird has coevolved with the tubular flower it pollinates. Only this species of bird can reach the nectar deep in the flower. What might happen to the flower if the bird species went extinct?

Timing of Macroevolution

Is evolution slow and steady? Or does it occur in fits and starts? It may depend on what else is going on, such as changes in climate and geologic conditions.

- When geologic and climatic conditions are stable, evolution may occur gradually. This is how Darwin thought evolution occurred. This model of the timing of evolution is called **gradualism**.
- When geologic and climatic conditions are changing, evolution may occur more quickly. Thus, long periods of little change may be interrupted by bursts of rapid change. This model of the timing of evolution is called **punctuated equilibrium**. It is better supported by the fossil record than is gradualism.

5.7 End of Chapter Review & Resources

Chapter Summary

Darwin's theory of evolution by natural selection states that living things with beneficial traits produce more offspring than others do. This produces changes in the traits of living things over time. During his voyage on the *Beagle*, Darwin made many observations that helped him develop his theory of evolution. His most important observations were made on the Galápagos Islands. Darwin was influenced by other early thinkers, including Lamarck, Lyell, and Malthus. He was also influenced by his knowledge of artificial selection. Wallace's paper on evolution confirmed Darwin's ideas. It also pushed him to publish his book, *On the Origin of Species.* The book clearly spells out his theory. It also provides evidence and logic to support it. Fossils provide a window into the past. They are evidence for evolution. Scientists who find and study fossils are called paleontologists. Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved. Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor. Other evidence is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job. Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution. On island chains, such as the Galápagos, one species may evolve into many new species to fill available niches. This is called adaptive radiation. Microevolution occurs over a short period of time in a population or species. Macroevolution occurs over geologic time above the level of the species. The population is the unit of evolution. A population's gene pool consists of all the genes of all the members of the population. For a given gene, the population is characterized by the frequency of different alleles in the gene pool. The Hardy-Weinberg theorem states that, if a population meets certain conditions, it will be in equilibrium. In an equilibrium population, allele and genotype frequencies do not change over time. The conditions that must be met are no mutation, no migration, very large population size, random mating, and no natural selection. There are four forces of evolution: mutation, gene flow, genetic drift, and natural selection. Natural selection for a polygenic trait changes the distribution of phenotypes. It may have a stabilizing, directional, or disruptive effect on the phenotype distribution. New species arise in the process of speciation. Allopatric speciation occurs when some members of a species become geographically separated. They then evolve genetic differences. If the differences prevent them from interbreeding with the original species, a new species has evolved. Sympatric speciation occurs without geographic separation. Coevolution occurs when species evolve together. This often happens in species that have symbiotic relationships. Examples include flowering plants and their pollinators. Darwin thought that evolution occurs gradually. This model of evolution is called gradualism. The fossil record better supports the model of punctuated equilibrium. In this model, long periods of little change are interrupted by bursts of rapid change.

Review Questions

1. State Darwin's theory of evolution by natural selection.
2. Describe two observations Darwin made on his voyage on the *Beagle* that helped him develop his theory of evolution.
3. What is the inheritance of acquired characteristics? What scientist developed this mistaken idea?
4. What is artificial selection? How does it work?
5. How did Alfred Russel Wallace influence Darwin?
6. Explain how the writings of Charles Lyell and Thomas Malthus helped Darwin develop his theory of evolution by natural selection.
7. How do paleontologists learn about evolution?
8. Describe what fossils reveal about the evolution of the horse.

9. What are vestigial structures? Give an example.
10. Define biogeography.
11. Describe an example of island biogeography that provides evidence of evolution.
12. Compare and contrast homologous and analogous structures. What do they reveal about evolution?
13. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.
14. Why does comparative embryology show similarities between organisms that do not appear to be similar as adults?
15. The Grants saw evolution occurring from one generation to the next in a population of finches.
    (a) What factors caused the short-term evolution the Grants witnessed? How did the Grants know that evolution had occurred?
    (b) What other factors do you think might cause evolution to occur so quickly within a population?
16. Why are populations, rather than individuals, the units of evolution?
17. What is a gene pool?
18. Describe a Hardy-Weinberg equilibrium population. What conditions must it meet to remain in equilibrium?
19. Identify the four forces of evolution.
20. Why is mutation needed for evolution to occur, even though it usually has little effect on allele frequencies?
21. What is founder effect? Give an example.
22. Compare and contrast microevolution and macroevolution. How are the two related?
23. Explain why genetic drift is most likely to occur in a small population.
24. Define speciation.
25. Describe how allopatric speciation occurs.
26. What is a species' niche? What do you think it might include besides the food a species eats?
27. Why is sympatric speciation less likely to occur than allopatric speciation?

Further Reading / Supplemental Links

- Berkeley University - Understanding Evolution: http://evolution.berkeley.edu/evolibrary/article/evo_-01
- PBS What is Evolution: http://www.pbs.org/wgbh/evolution/library/faq/cat01.html
- The American Museum of Natural history - Hall of Human Origins http://www.amnh.org/exhibitions/permanent
- Harvard University - Department of Organismic and Evolutionary Biology - http://www.oeb.harvard.edu/

Vocabulary to Know

- artificial selection
- fitness
- Galápagos Islands
- inheritance of acquired characteristics
- adaptive radiation
- analogous structure
- biogeography
- comparative anatomy
- comparative embryology
- homologous structure
- paleontologist

- vestigial structure
- allele frequency
- directional selection
- disruptive selection
- gene flow
- gene pool
- genetic drift
- Hardy-Weinberg theorem
- macroevolution
- microevolution
- population genetics
- sexual dimorphism
- stabilizing selection
- allopatric speciation
- coevolution
- gradualism
- punctuated equilibrium
- speciation
- sympatric speciation

References

Credits

Chapter 6

The Principles of Ecology

6.1 Introduction

These brilliant red "feathers" are actually animals called tube worms. They live in an extreme environment on the deep ocean floor, thousands of meters below the water's surface. Their world is always very cold and completely dark. Without sunlight, photosynthesis is not possible. So what do organisms eat at these depths? Tube worms depend on chemosynthetic microorganisms that live inside them for food. In this and other ways, tube worms have adapted to the extreme conditions of their environment. All organisms must adapt to their environment in order to survive. This is true whether they live in water or on land. Most environments are not as extreme as the deep ocean where tube worms live. But they all have conditions that require adaptations. In this chapter, you will read about a wide variety of environments and the organisms that live in them. Photosynthesis and cellular respiration are important for recycling oxygen and creating the energy for life.

Chapter Objectives

- Distinguish between abiotic and biotic factors.

- Define ecosystem and other ecological concepts.
- Describe how energy flows through ecosystems.
- Explain how food chains and webs model feeding relationships.
- Identify trophic levels in a food chain or web.
- Define and give examples of biogeochemical cycles that recycle matter.
- Describe the water cycle and the processes by which water changes state.
- Summarize the organic and geological pathways of the carbon cycle.
- Outline the nitrogen cycle and state the roles of bacteria in the cycle.
- State the significance of the community in ecology, and list types of community interactions.
- Define predation, and explain how it affects population growth and evolution.
- Describe competition, and outline how it can lead to extinction or specialization of species.
- Define symbiosis, and identify major types of symbiotic relationships.
- Describe ecological succession, and explain how it relates to the concept of a climax community

6.2 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.

As you already learned, 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.

6.3 Five Laws of Ecology

According to Barry Commoner, there are Four Laws of Ecology (as follows). Explain how his laws govern the way nature works.

- Everything is connected to everything else.

  Simple put, we are living on large global system. It is a closed system, at least until we figure out how to get natural resources from other planets. Much like your body is an interconnected system of small systems, all networked together to work in harmony. The Earth is the same. Affect the Oceans dramatically in one place and it could affect other parts of the Earth. Deforestation in one area could affect the water cycle in other regions. Everything is connected.

- Everything must go somewhere.

  Where does your garbage go? Imagine how much you throw away. What happens to it? Who or what does it affect? When you pour something down the drain of your home, where does it go? Nature has complex systems that help break down matter into its smallest components so that more life may use them. Humans, though, create a lot of non-biodegradable items that go into the environment. Everything a human creates must, at some point, go somewhere. Where?

- Nature knows best.

  Billions of years have created the complex, intricate, and amazing ecosystem services, good, resources, and systems that humans rely upon for life and food.

- There is no such thing as a free lunch.

  Nothing is free. As you learned in the chapter about energy: energy is neither created nor destroyed. It just changes shape. Nothing is free, and nothing can be created out of nothing.

- Everything has limits.

  No natural resource or energy source is limitless. We are using renewable natural resources at rates faster than they can replenish themselves, deteriorating our land through erosion, emptying our water reservoirs, and depleting non-renewable resources.

The laws of ecology serve to remind us of our place within our natural systems, and that humans are, ultimately, an animal too that must adhere to the natural rules that govern the planet. They are rules about how all life on Earth functions, and what factors to consider in our daily lives, social development, land use, and business practices.

> *Critical Thinking*: A ecological footprint is an evaluation of how much effect a person has on the environment. It is defined as the measure of your demand on natural resources and the Earth's natural systems. What is your ecological footprint? You can find out by going to the Global Footprint Network and using their form to calculate your ecological footprint:
>
> www.footprintcalculator.org

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** 6.1. 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.

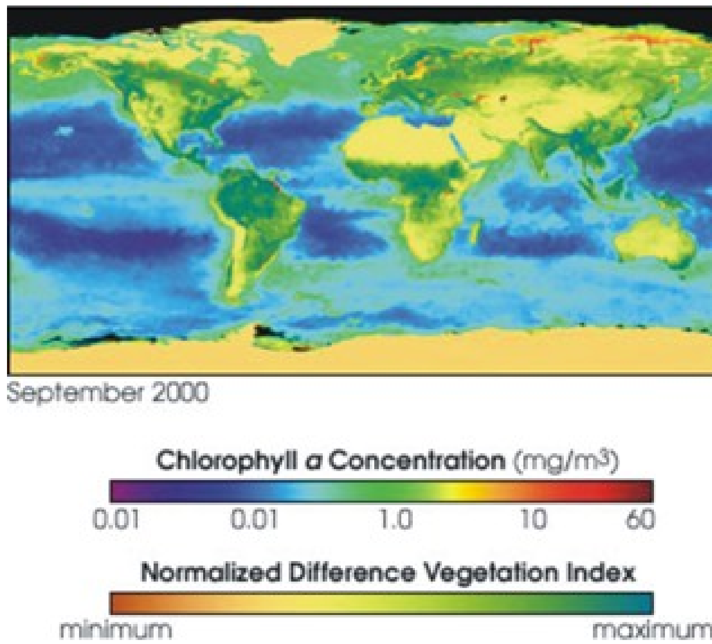

Figure 6.1: This image of Earth

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** 6.2.

Figure 6.2: 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** 6.3. 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.

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. Habitat destruction caused the extinction of the dusky seaside sparrow shown in **Figure ??**. Many other bird species are currently declining worldwide. More than 1,200 species face extinction during the next century due mostly to habitat loss and climate change.

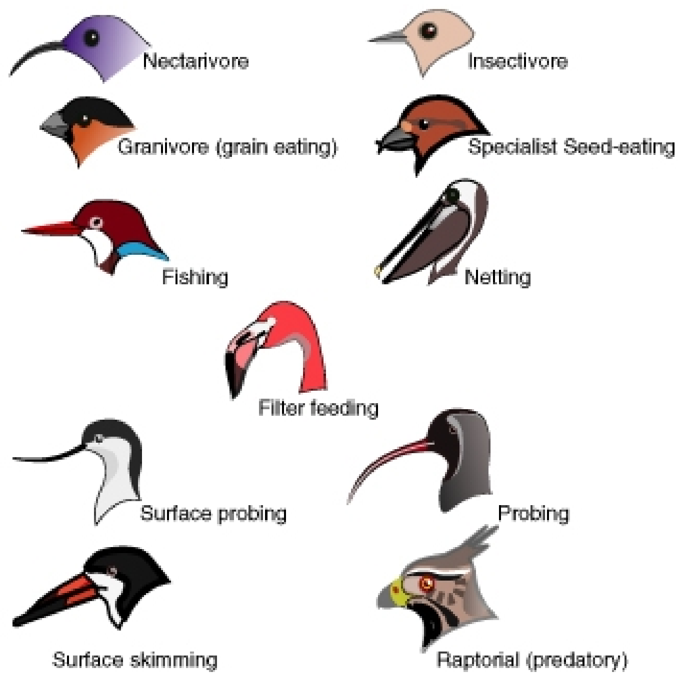

Figure 6.3: Bird Niches. Each of these species of birds has a beak that suits it for its niche. For example, the long slender beak of the nectarivore allows it to sip liquid nectar from flowers. The short sturdy beak of the granivore allows it to crush hard, tough grains.

Competitive Exclusion Principle

A given habitat may contain many different species, but each species must have a different niche. Two different species cannot occupy the same niche in the same place for very long. This is known as the **competitive exclusion principle**. If two species were to occupy the same niche, what do you think would happen? They would compete with one another for the same food and other resources in the environment. Eventually, one species would be likely to outcompete and replace the other.

6.4 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** 6.6).
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 (H_2S). Oxidation is an energy-releasing chemical reaction in which a molecule, atom, or ion loses electrons.

Chemoautotrophs include bacteria called nitrifying bacteria, which you will read more about in Lesson 3. Nitrifying bacteria 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** 6.4, 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** 6.5. Why do bacteria that live deep below the ocean’s surface rely on chemical compounds instead of sunlight for energy to make food?

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

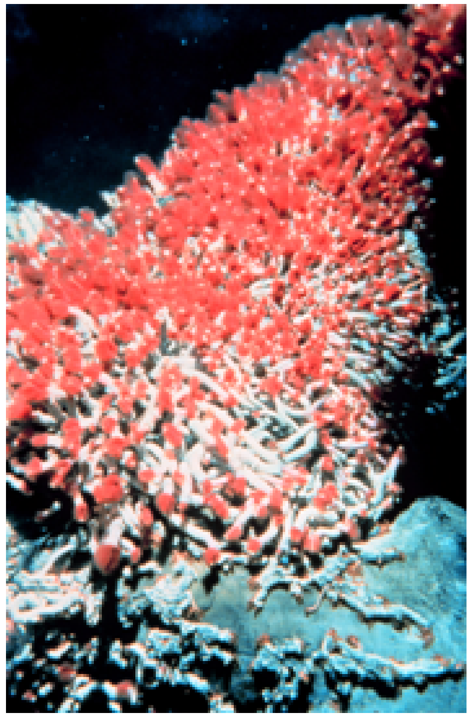

Figure 6.4: Red tube worms, each containing millions of archaea microorganisms, grow in a cluster around a hydrothermal vent in the deep ocean floor. Archaea produce food for themselves (and for the tube worms) by chemosynthesis.

Figure 6.5: Tubeworms deep in the Gulf of Mexico get their energy from chemosynthetic bacteria. The bacteria actually live inside the worms.

other organisms for energy. As shown in **Figure ??**, 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.

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 ??**. 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.

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** 6.8). In water, detritivores include "bottom feeders" such as sea cucumbers and catfish.

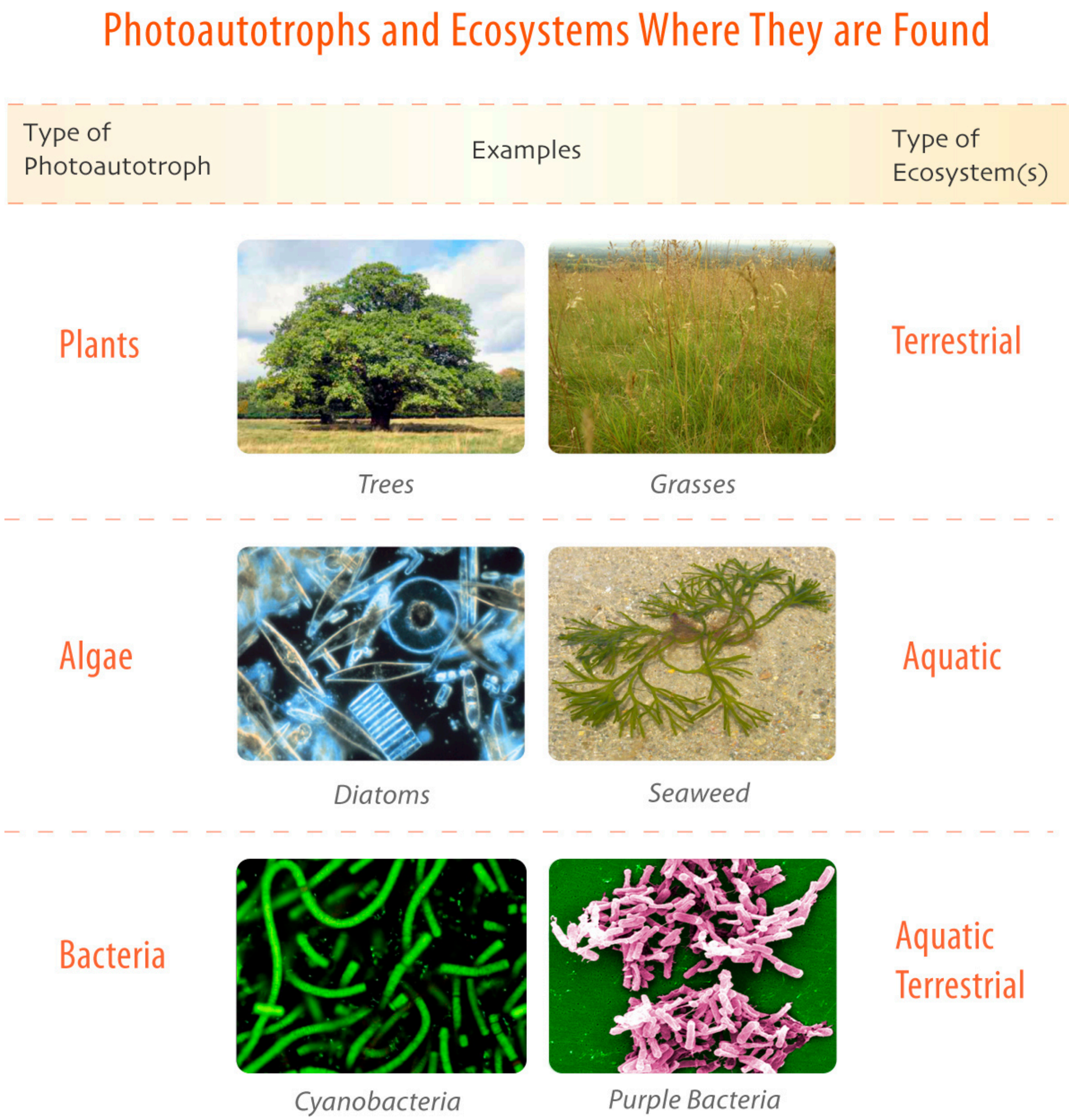

Figure 6.6: Different types of photoautotrophs are important in different ecosystems.

Figure 6.7: 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.

- **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 6.8: Dung Beetle. This dung beetle is rolling a ball of feces to its nest to feed its young.

6.5 Making and Using Food: Photosynthesis and Cellular Respiration

The flow of energy through living organisms begins with **photosynthesis**. This process stores energy from sunlight in the chemical bonds of glucose. By breaking the chemical bonds in glucose, cells release the stored energy and make the ATP they need. The process in which glucose is broken down for energy is called **cellular respiration**. Photosynthesis and cellular respiration are like two sides of the same coin. This is apparent from **Figure** 6.9. The products of one process are the reactants of the other. Together, the two processes store and release energy in living organisms. The two processes also work together to recycle oxygen in Earth's atmosphere.

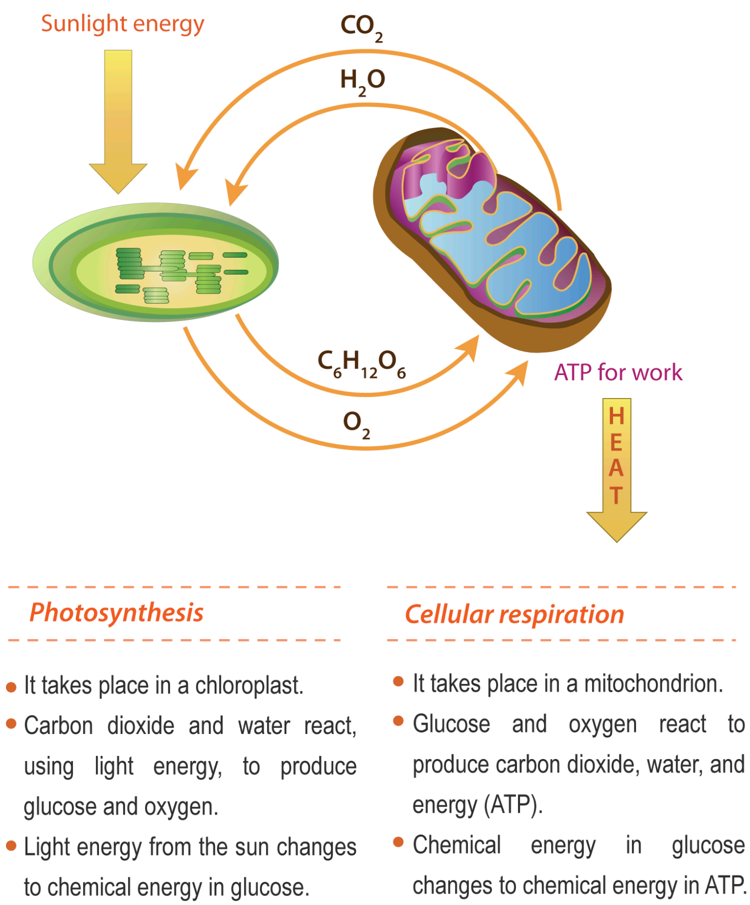

Figure 6.9: This diagram compares and contrasts photosynthesis and cellular respiration. It also shows how the two processes are related.

Photosynthesis

Plants and other autotrophs make food out of "thin air"—at least, they use carbon dioxide from the air to make food. Most food is made in the process of photosynthesis. This process provides more than 99% of the energy used by living things on Earth. Photosynthesis also supplies Earth's atmosphere with oxygen.

Photosynthesis is often considered to be the single most important life process on Earth. It changes light energy into chemical energy and also releases oxygen. Without photosynthesis, there would be no oxygen in the atmosphere. During photosynthesis, raw materials are used to manufacture sugar (glucose). Photosynthesis occurs in the presence of chlorophyll, a green plant pigment that helps the plant utilize the energy from sunlight to drive the process. Although the overall process involves a series of reactions, the net reaction can be represented by the following:

$$\underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{6H_2O} + \underset{\text{(sunlight)}}{\text{Energy}} \rightarrow \underset{\text{(sugar)}}{C_6(H_2O)_6} + \underset{\text{(oxygen)}}{6O_2}$$

Figure 6.10

Photosynthetic autotrophs (such as plants) capture light energy from the sun and absorb carbon dioxide and water from their environment. Using the light energy, they combine the reactants to produce glucose and oxygen, which is a waste product. They store the glucose, usually as starch, and they release the oxygen into the atmosphere. The sugar provides a source of energy for other plant processes and is also used for synthesizing materials necessary for plant growth and maintenance. The net effect with regard to carbon is that it is removed from the atmosphere and incorporated into the plant as organic materials.

Photosynthesis occurs in two stages: the Light Reactions and the Calvin Cycle, which both take place in the chloroplast of plants and other chlorophyll containing organisms.

Photosynthesis Stage I: The Light Reactions

The first stage of photosynthesis is called the light reactions. During this stage, light is absorbed and transformed to chemical energy. By the end of stage 1, energy from sunlight has been changed to chemical energy, and the first stage of photosynthesis is now complete.

Photosynthesis Stage II: The Calvin Cycle

The reactions of this stage can occur without light, so they are sometimes called light-independent or dark reactions. This stage of photosynthesis is also known as the Calvin cycle because its reactions were discovered by a scientist named Melvin Calvin. He won a Nobel Prize in 1961 for this important discovery. In the Calvin cycle, chemical energy from the light reactions is used to make glucose. The Calvin cycle takes over where the light reactions end. It uses stored chemical energy (from the light reactions) and carbon dioxide from the air to produce glucose, the molecule that virtually all organisms use for food.

The Chloroplast: Theater for Photosynthesis

The "theater" where both stages of photosynthesis take place is the chloroplast. Chloroplasts are organelles that are found in the cells of plants and algae. (Photosynthetic bacteria do not have chloroplasts, but they contain structures similar to chloroplasts and produce food in the same way.) Look at the **Figure** 6.12. The figure is a high power microscopic photo of the upper part of a Winter Jasmine leaf. If you could look at a single leaf of this plant under a microscope, you would see small green ovals, like those shown. These small green ovals are chloroplasts.

Cellular Respiration

You have just read how photosynthesis stores energy in glucose. How do living things make use of this stored energy? The answer is cellular respiration. This process releases the energy in glucose to make ATP, the molecule that powers all the work of cells.

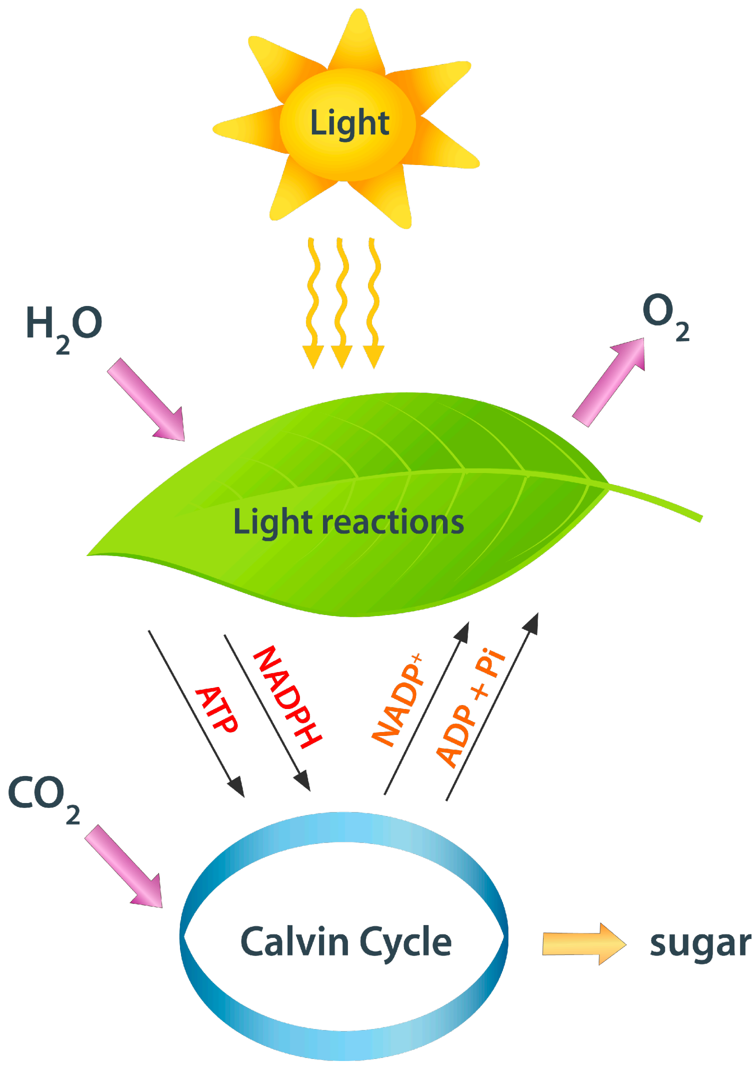

Figure 6.11: The two stages of photosynthesis are the light reactions and the Calvin cycle. Do you see how the two stages are related?

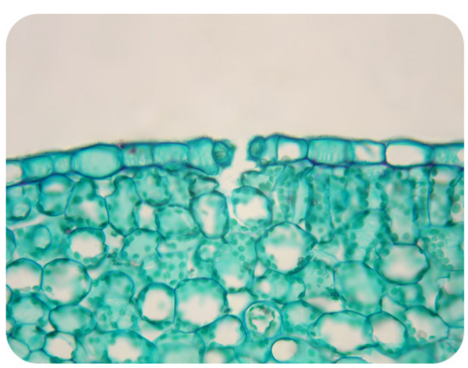

Figure 6.12: High power microscopic photo of the upper part of a Winter Jasmine leaf. Viewed under a microscope many green chloroplasts are visible.

The reciprocal process of photosynthesis is called respiration. Cellular respiration actually ‘‘burns” glucose for energy. However, it doesn’t produce light or intense heat as some other types of burning do. This is because it releases the energy in glucose slowly, in many small steps. The net result of this process is that sugar is broken down by oxygen into carbon dioxide and water. Cellular respiration involves many chemical reactions, which can be summed up with this chemical equation:

$$\boxed{\underset{\text{(sugar)}}{C_6(H_2O)_6} + \underset{\text{(oxygen)}}{6O_2} \rightarrow \underset{\left(\substack{\text{carbon}\\ \text{dioxide}}\right)}{6CO_2} + \underset{\text{(water)}}{6H_2O} + \text{Energy}}$$

Figure 6.13

Cellular respiration occurs in the cells of all living things. This process occurs not only in plants, but also in humans and animals. So, unlike photosynthesis, respiration can occur during both the day and night. During respiration, carbon is removed from organic materials and expelled into the atmosphere as carbon dioxide.

Anaerobic vs. Aerobic Respiration

Cellular respiration that proceeds without oxygen is called **anaerobic respiration**, and this was probably the first kind of respiration present in organisms before oxygen levels increased in the atmosphere. About 2 or 3 billion years ago, oxygen was gradually added to the atmosphere by early photosynthetic bacteria. After that, living things could use oxygen for respiration. Cellular respiration that proceeds in the presence of oxygen is called **aerobic respiration**.

Today, most living things use oxygen to make energy from glucose (aerobic respiration). However, many living things can still also make energy for life without oxygen. This is true of some plants and fungi and also of many bacteria. These organisms use aerobic respiration when oxygen is present, but when oxygen is in short supply, they use anaerobic respiration instead. Certain bacteria can only use anaerobic respiration. In fact, they may not be able to survive at all in the presence of oxygen.

Fermentation

An important way of making energy without oxygen is called **fermentation**. Many bacteria and yeasts carry out fermentation. People use these organisms to make yogurt, bread, wine, and biofuels. Human muscle cells also use fermentation. This occurs when muscle cells cannot get oxygen fast enough to meet their energy needs through aerobic respiration. There are two types of fermentation: **lactic acid fermentation** and **alcoholic fermentation**.

Lactic acid fermentation is carried out by the bacteria in yogurt. It is also used by your own muscle cells when you work them hard and fast. Did you ever run a race and notice that your muscles feel tired and sore afterward? This is because your muscle cells used lactic acid fermentation for energy. This causes lactic acid to build up in the muscles. It is the buildup of lactic acid that makes the muscles feel tired and sore.

A**lcoholic fermentation** is carried out by yeasts and some bacteria. It is used to make bread, wine, and biofuels. Have your parents ever put corn in the gas tank of their car? They did if they used gas containing ethanol. Ethanol is produced by alcoholic fermentation of the glucose in corn or other plants. This type of fermentation also explains why bread dough rises. Yeasts in bread dough use alcoholic fermentation and produce carbon dioxide gas. The gas forms bubbles in the dough, which cause the dough to expand. The bubbles also leave small holes in the bread after it bakes, making the bread light and fluffy. Do you see the small holes in the slice of bread in **Figure** 6.14?

Figure 6.14: The small holes in bread are formed by bubbles of carbon dioxide gas. The gas was produced by alcoholic fermentation carried out by yeast.

6.6 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** 6.15. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.

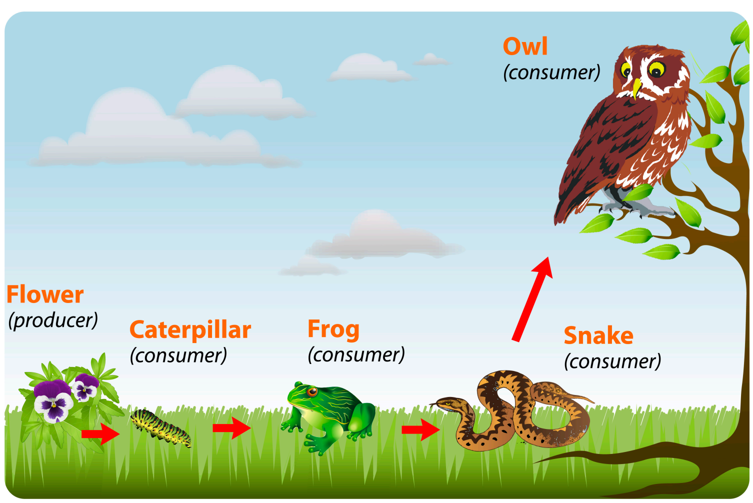

Figure 6.15: This food chain includes producers and consumers. How could you add decomposers to the food chain?

A musical summary of food chains can be heard at http://www.youtube.com/watch?v=TE6wqG4nb3M (2:46).

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** 6.16.

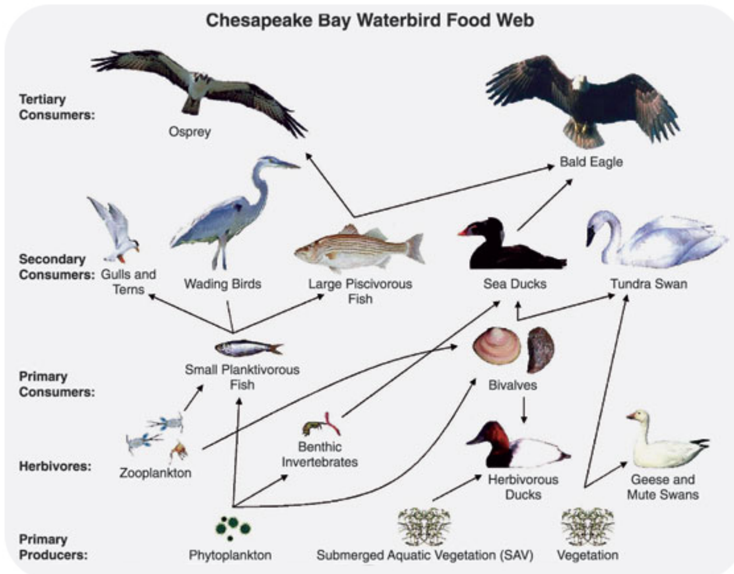

Figure 6.16: Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

Trophic Levels

The feeding positions in a food chain or web are called **trophic levels**. The different trophic levels are defined in **Table** 6.1. 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.

Table 6.1: **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** 6.17.

Pyramid of Energy

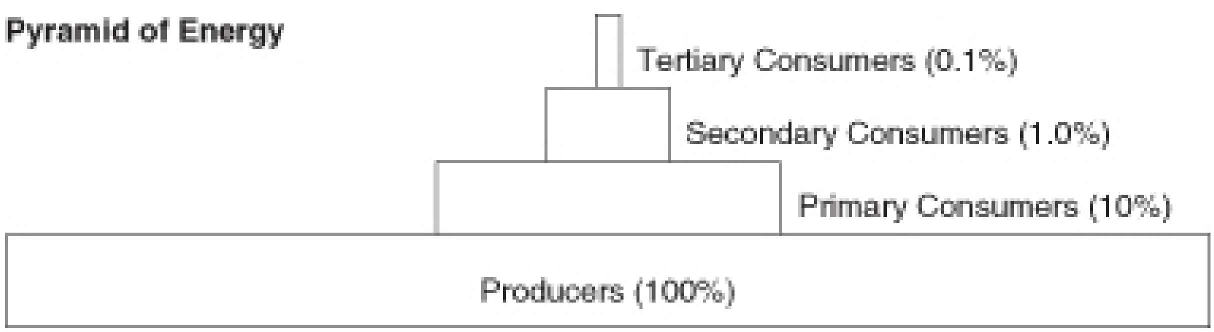

Figure 6.17: This pyramid shows the total energy stored in organisms at each trophic level in an ecosystem. Starting with primary consumers, each trophic level in the food chain has only 10 percent of the energy of the level below it. The pyramid makes it clear why there can be only a limited number of trophic levels in a food chain or web.

Trophic Levels and Biomass

With less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers result in less biomass. **Biomass** is the total mass of organisms at a trophic level. The decrease in biomass from lower to higher levels is also represented by **Figure** 6.18.

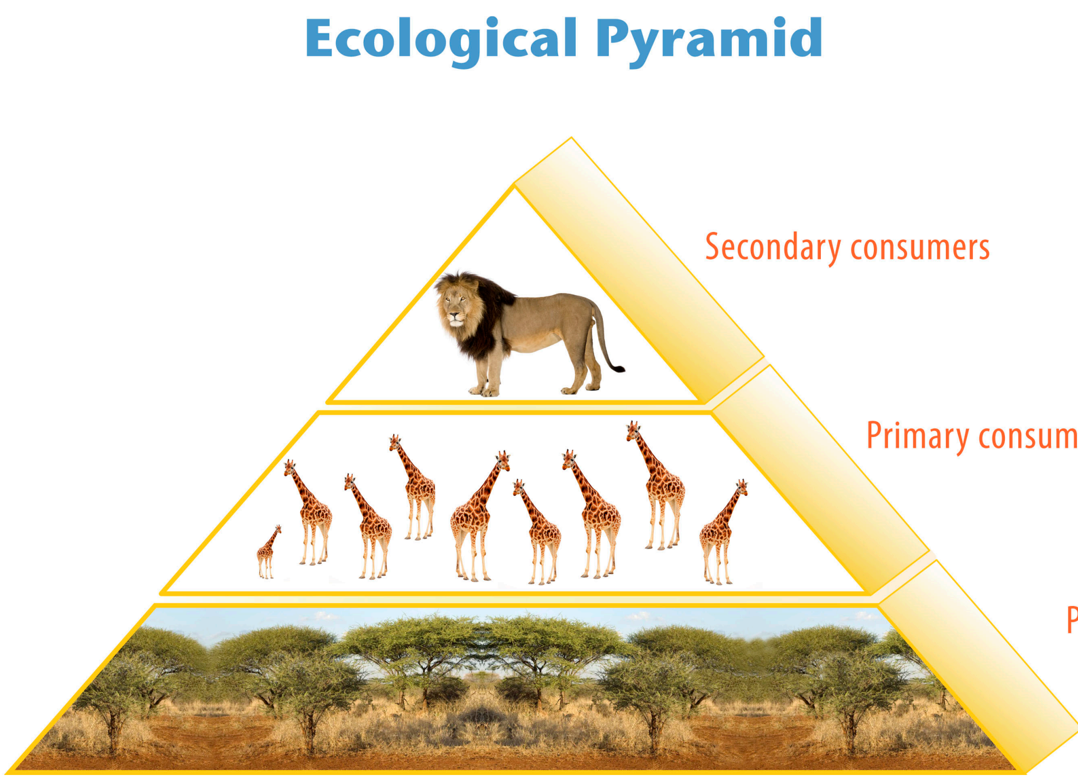

Figure 6.18: Ecological Pyramid. This pyramid shows how energy and biomass decrease from lower to higher trophic levels. Assume that producers in this pyramid have 1,000,000 kilocalories of energy. How much energy is available to primary consumers?

6.7 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 1** 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 (see the *Principles of Ecology* chapter).

Figure 6.19: 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 1** 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**. 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.

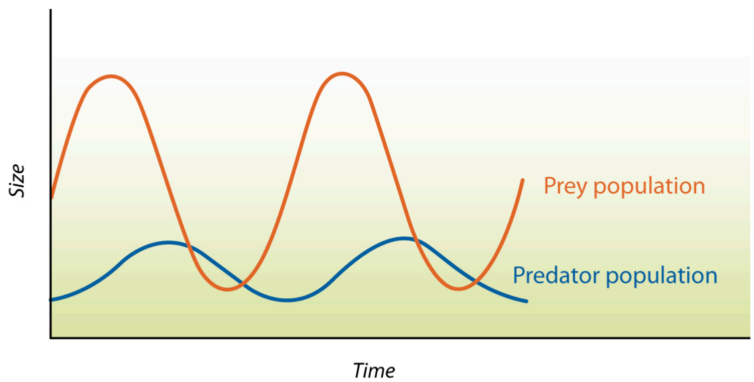

Figure 6.20: As the prey population increases, the predator population starts to rise. With more predators, the prey population starts to decrease, which, in turn, causes the predator population to decline. This pattern keeps repeating. There is always a slight lag between changes in one population and 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 3**.

Figure 6.21: 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.

Another way of using camouflage is to look like a different, more dangerous animal. Using appearance to "mimic" another animal is called **mimicry.** **Figure 4** 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 6.22: The moth on the left mimics the owl on the right. This

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.

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 5**. 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 6.23: 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**.

1. **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 6**). 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. For example, the plant with tube-shaped flowers shown in **Figure 7** co-evolved with hummingbirds. The birds evolved long, narrow beaks that allowed them to sip nectar from the tubular bloom.

Table 6.2: **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.**

title

2. **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.

3. **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.

Ecological Succession

Ecological succession is the process by which a whole community of populations changes through time. It occurs following a disturbance that creates unoccupied areas for colonization. The first colonizer species are called **pioneer species.** They change the environment and pave the way for other species to move into the area. Succession occurs in two different ways, depending on the starting conditions: primary succession and secondary succession.

Primary succession occurs in an area that has never been colonized before. Generally, the area is nothing but bare rock. This type of environment can come about in a number of ways, including:

- Lava can flow from a volcano and harden into rock.
- A glacier can retreat and leave behind bare rock.
- A landslide can uncover a large area of bare rock.

After the disturbance, pioneer species move in first. They include bacteria and lichens that can live on bare rock. Along with wind and water, these pioneer species help to weather the rock and form soil. Once soil begins to form, other plants can move in. At first, the plants include grasses and other species that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. This improves the soil and helps it hold water. The improved soil allows shrubs and trees to move into the area. An example of primary succession is shown in **Figure 8**.

Secondary succession occurs in a formerly inhabited area that was disturbed. The disturbance could be a fire, flood, or human action such as logging or farming. Secondary succession can occur faster than primary succession because the soil is already in place. In secondary succession, the pioneer species are plants that are adapted to exploit disturbances rather than bare rock. They typically include plants such as grasses, birch trees, and fireweed. Organic matter from the pioneer species improves the soil so other trees and plants can move into the area. An example of secondary succession is shown in **Figure 9**.

Figure 6.24: On an island near New Zealand, bare rocks from a volcanic eruption are slowly being colonized by pioneer species.

Figure 6.25: This formerly cultivated farm field in Poland is reverting to deciduous forest in the process of secondary succession.

Climax Communities

Many early ecologists thought that a community always went through a predictable series of stages during succession. They also thought that the end result of succession was a final stage called a **climax community.** The type of climax community was believed to be determined mainly by climate. For example, in mild, wet temperate climates, evergreen rainforests were thought to be the predictable end result of succession. Climax communities were also thought to be very biodiverse. This characteristic, in turn, was believed to make them stable, or resistant to change.

Today, most ecologists think that change, rather than stability, is more characteristic of ecological systems. They argue that most communities are disturbed too often to reach a climax community stage. They also argue that high biodiversity does not always make a community stable. Some communities that have low biodiversity, such as salt marshes, are very resistant to change. On the other hand, some communities that have high biodiversity, such as coral reefs, are easily affected by disturbances. High biodiversity may increase species interactions. This, in turn, may make species more interdependent and communities more likely to change when they are disturbed.

6.8 End of Chapter Review & Resources

Chapter Summary

Ecology is the study of how living things interact with each other and with their environment. The environment includes abiotic (nonliving) and biotic (living) factors. An ecosystem consists of all the biotic and abiotic factors in an area and their interactions. A niche refers to the role of a species in its ecosystem. A habitat is the physical environment in which a species lives and to which it is adapted. Two different species cannot occupy the same niche in the same place for very long. Ecosystems require constant inputs of energy from sunlight or chemicals. Producers use energy and inorganic molecules to make food. Consumers take in food by eating producers or other living things. Decomposers break down dead organisms and other organic wastes and release inorganic molecules back to the environment. Food chains and food webs are diagrams that represent feeding relationships. They model how energy and matter move through ecosystems. The different feeding positions in a food chain or web are called trophic levels. Generally, there are no more than four trophic levels because energy and biomass decrease from lower to higher levels. Living things need energy to carry out all life processes. They get energy from food. Autotrophs make their own food. Heterotrophs get food by eating other living things. Most autotrophs make food using photosynthesis. This process occurs in two stages: the light reactions and the Calvin cycle. Some bacterial autotrophs make food using chemosynthesis. This process uses chemical energy instead of light energy to produce food. Many autotrophs make food through the process of photosynthesis, in which light energy from the sun is changed to chemical energy that is stored in glucose. All organisms use cellular respiration to break down glucose, release energy. Living things must have chemical energy from food to power life processes. Most of the chemical energy in food comes ultimately from the energy in sunlight. The last two stages of aerobic respiration require oxygen. However, not all organisms live in places where there is a plentiful supply of oxygen so they use anaerobic respiration instead, which does not require oxygen. Competition among species is an important factor in co-evolution. The Four Laws of Ecology are important reference points about ecosystems and natural communities function, and are the basis for the balanced and sustained ways that natural systems are supported.

Review Questions

1. Define biotic and abiotic factors of the environment. Give an example of each.
2. How do ecologists define the term *ecosystem*?
3. State the competitive exclusion principle.
4. What is a producer? Name two examples.
5. What is an autotroph? Give an example.
6. What is an hetrotroph? Give an example.
7. Identify three different types of consumers. Name an example of each type.
8. Describe the role of decomposers in food webs.
9. Draw a terrestrial food chain that includes four trophic levels. Identify the trophic level of each organism in the food chain.
10. Compare and contrast the ecosystem concepts of niche and habitat.
11. What can you infer about an ecosystem that depends on chemoautotrophs for food?
12. Explain how energy limits the number of trophic levels in a food chain or web.
13. What are the stages of photosynthesis? Which stage occurs first?
14. Describe the chloroplast and its role in photosynthesis.
15. What is fermentation? Name two types of fermentation.
16. What process produces fuel for motor vehicles from living plant products? What is the waste product of this process?

17. Compare and contrast photosynthesis and cellular respiration. Why are the processes like two sides of the same coin?
18. Explain how living things recycle oxygen in Earth's atmosphere.
19. The first living things appeared on Earth at least a billion years before photosynthetic organisms appeared. How might the earliest organisms have obtained energy before photosynthesis evolved? What process could they have used to make food?
20. In ecology, what is a community?
21. Define predation and give an example of a predator and its prey.
22. What are two possible outcomes of interspecific competition?
23. List three basic types of symbiotic relationships.
24. What is ecological succession and when does it occur?
25. A forest was recently disturbed, and several pioneer species have moved in. Which type of ecological succession is taking place? How do you know?
26. Why do species interactions often lead to co-evolution of the species involved? Give an example to illustrate your answer.
27. Understand the Four Laws of Ecology and how they apply to ecosystems. How should they apply to human actions?

Further Reading / Supplemental Links

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Vocabulary to Know

- abiotic factor
- biomass
- biological pest control - Deliberate introduction of a predator species into an area in order to control a pest species.
- biotic factor
- camouflage - Common adaptation in predator and prey species that involves disguise.
- carnivore
- cellular respiration - The process by which cells oxidize glucose and produce carbon dioxide, water, and energy.
- chemoautotroph
- climax community - Final stage of ecological succession.
- co-evolution - Evolution of interacting species in which each species is an important factor in the natural selection of the other species.

- commensalism - Symbiotic relationship in which one species benefits while the other species is not affected.
- community - Biotic component of an ecosystem.
- competition - Relationship between organisms that strive for the same limited resources.
- competitive exclusion principle
- decomposer
- detritivore
- detritus
- ecological succession - Process by which a whole community changes through time following a disturbance.
- ecology
- Ecosystem
- food chain
- food web
- grazing - Type of predation in which the predator eats part of its prey but rarely kills it.
- habitat
- herbivore
- intraspecific competition - Competition between members of the same species.
- interspecific competition - Competition between members of different species.
- keystone species - Predator species that plays an important role in the community by controlling the prey population and, indirectly, the populations of many other species in the community.
- mimicry - Using appearance to "mimic" another animal.
- mutualism - Symbiotic relationship in which both species benefit.
- omnivore
- parasitism - Symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed.
- photoautotroph
- pioneer species - First colonizer species in an area undergoing ecological succession.
- predation - Relationship in which members of one species (the predator) consume members of other species (the prey).
- primary succession - Ecological succession that occurs in an area that has never been colonized before.
- saprotroph
- scavenger
- secondary succession - Ecological succession that occurs in a formerly inhabited area that was disturbed.
- symbiosis - Close association between two species in which at least one species benefits.
- trophic level
- true predation - Type of predation in which the predator kills its prey.

Chapter 7

World Biomes

7.1 Introduction

Around the world there are unique climatic conditions that contribute to unique eocysystems. There are patterns in the types of ecosystems around the world called biomes. There are terrestrial biomes, that span the arctic, temperate, and tropical regions. There are also fresh water, costal and marine aquatic biomes, which make up about 70% of the world's biomes.

Chapter Objectives

- Define biome and climate, and explain how biomes are related to climate.
- Outline how climate determines growing conditions for plants and affects the number and biodiversity of plants in a biome.
- Explain how climate is related to biodiversity of biomes and adaptations of organisms.
- State how terrestrial biomes are classified and distributed around the globe.
- Outline abiotic and biotic factors in tundra and boreal forest biomes.
- Describe climatic factors and organisms of temperate zone biomes.
- List abiotic factors in deserts and adaptations of desert organisms.
- Identify abiotic factors and organisms in tropical biome.
- Describe how aquatic biomes are divided into zones, and list types of aquatic organisms.
- Identify marine biomes, and state which biomes have the highest biodiversity.
- Name types of freshwater biomes, and describe how they differ from one another.

7.2 Biomes and Climate

If you look at the two pictures in **Figure 1** below, you will see very few similarities. The picture on the left shows a desert in Africa. The picture on the right shows a rainforest in Australia. What is the most obvious difference between the two places? It could be that the desert does not have any visible plants, whereas the rainforest is densely packed with trees. What causes these two places to be so different? The main reason is climate.

Figure 7.1: Sahara Desert in northern Africa (left). Rainforest in northeastern Australia (right).

The two pictures above represent two different types of biomes: deserts and rainforests. A **biome** is a group of similar ecosystems that cover a broad area. Biomes are major subdivisions of the biosphere. They can be classified into two major types:

- **Terrestrial biomes**: biomes on land
- **Aquatic biomes**: biomes in water

You will read about terrestrial biomes in Lesson 16.2 and aquatic biomes in Lesson 16.3. First, however, it is important to understand how climate influences biomes. Climate is the most important abiotic (non-living) factor affecting the distribution of terrestrial biomes of different types. Climate determines the growing conditions in an area, so it also determines what plants can grow there. Animals depend directly or indirectly on plants, so the type of animals that live in an area also depends on climate.

What Is Climate?

Climate is the average weather in an area over a long period of time, whereas weather is a day to day explanation. Weather and climate are described in terms of factors such as temperature and precipitation. The climate of a particular location depends, in turn, on its latitude (distance from the equator) and altitude (distance above sea level). Other factors that affect an area's climate include its location relative to the ocean or mountain ranges. Temperature and moisture are the two climatic factors that most affect terrestrial biomes.

Temperature

In general, temperature on Earth's surface falls from the equator to the poles. Based on temperature, climates can be classified as tropical, temperate, or arctic, as shown in **Figure 2**. Temperature also falls from lower to higher altitudes, for example, from the base of a mountain to its peak. This explains why the tops of high mountains in tropical climates may be snow-capped year-round.

The ocean may also play an important role in the temperature of an area. Coastal areas may have milder climates than areas farther inland at the same latitude. This is because the temperature of the ocean

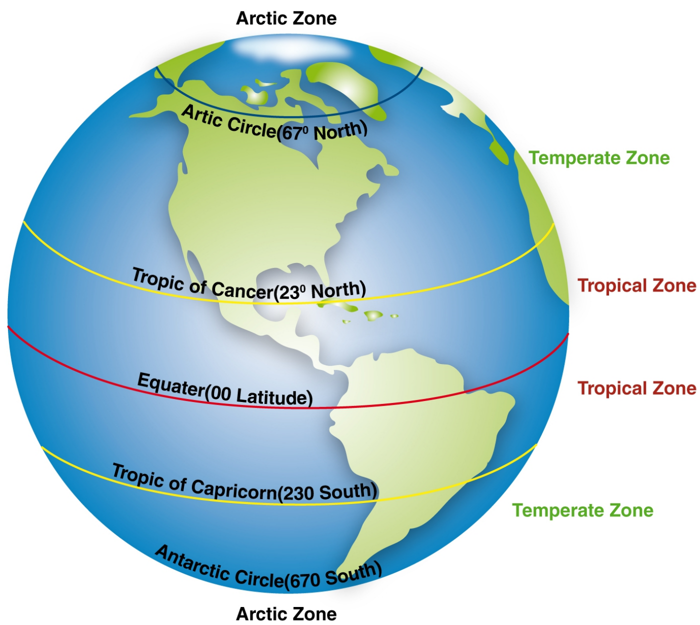


Figure 7.2: Major climate zones based on temperature include tropical, temperate, and arctic zones. The tropical zone extends from the Tropic of Capricorn to the Tropic of Cancer. The two temperate zones extend from the tropical zone to the arctic or antarctic circle. The two arctic zones extend from the arctic or antarctic circle to the north or south pole.

changes relatively little from season to season, and this affects the temperature on nearby coasts. As a result, many coastal areas have both warmer winters and cooler summers than inland areas.

Moisture

Based on the amount of water available to plants, climates can be classified as arid (dry), semi-arid, semi-humid, or humid (wet). The moisture of a biome is determined by both precipitation and evaporation. Evaporation, in turn, depends on heat from the sun. Worldwide precipitation patterns result from global movements of air masses and winds, which are shown in **Figure 3**. For example, warm, humid air masses rise over the equator and are moved north and south by global air currents. The air masses cool and cannot hold as much water. As a result, they drop their moisture as precipitation. This explains why many tropical areas receive more precipitation than other areas of the world.

When the same air masses descend at about 30° north or south latitude (see **Figure 3**), they are much drier. This explains why dry climates are found at these latitudes. These latitudes are also warm and sunny, which increases evaporation and dryness. Dry climates are found near the poles, as well. Extremely cold air can hold very little moisture, so precipitation is low in arctic zones. However, these climates also have little evaporation because of the extreme cold. As a result, cold climates with low precipitation may not be as dry as warm climates with the same amount of precipitation.

Distance from the ocean and mountain ranges also influences precipitation. For example, one side of a mountain range near the ocean may receive a lot of precipitation because warm, moist air masses regularly move in from the water. As air masses begin to rise up over the mountain range, they cool and drop their moisture as precipitation. This is illustrated in **Figure 4**.

By the time the air masses reach the other side of the mountain range, they no longer contain moisture.

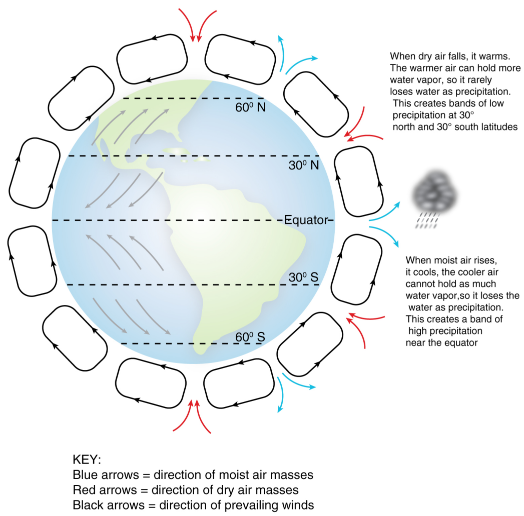


Figure 7.3: This model of Earth shows the direction in which air masses typically move and winds usually blow at different latitudes. These movements explain why some latitudes receive more precipitation than others.

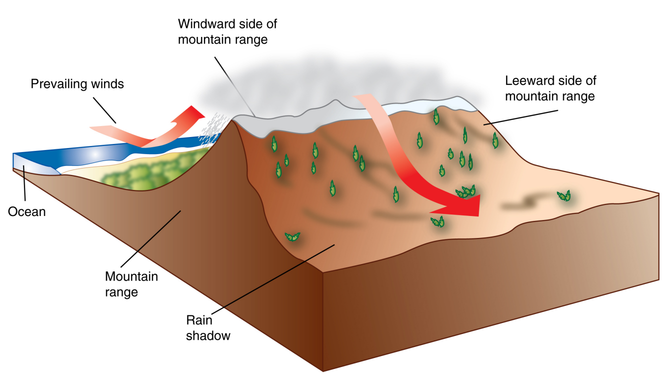


Figure 7.4: The windward side of this mountain range has a humid climate, whereas the leeward side has an arid climate. On the windward side, warm moist air comes in from the ocean, rises and cools, and drops its moisture as rain or snow. On the leeward side, the cool dry air falls, warms, and picks up moisture from the land. How has this affected plant growth on the two sides of the mountain range?

As a result, land on this side of the mountain range receives little precipitation. This land is in the **rain shadow** of the mountain range. Many inland areas far away from the ocean or mountain ranges are also dry. Air masses that have passed over a wide expanse of land to reach the interior of a continent usually no longer carry much moisture.

Climate and Plant Growth

Plants are the major producers in terrestrial biomes. Almost all other terrestrial organisms depend on them either directly or indirectly for food. Plants need air, warmth, sunlight, water, and nutrients to grow. Climate is the major factor affecting the number and diversity of plants that can grow in a terrestrial biome. Climate determines the average temperature and precipitation, the length of the growing season, and the quality of the soil, including levels of soil nutrients.

Growing Season

The **growing season** is the period of time each year when it is warm enough for plants to grow. The timing and length of the growing season determine what types of plants can grow in an area. For example, near the poles the growing season is very short. The temperature may rise above freezing for only a couple of months each year. Because of the cold temperatures and short growing season, trees and other slow-growing plants are unable to survive. The growing season gets longer from the poles to the equator. Near the equator, plants can grow year-round if they have enough moisture. A huge diversity of plants can grow in hot, wet climates.

The timing of precipitation also affects the growing season. In some areas, most of the precipitation falls during a single wet season (such as in California), rather than throughout the year (such as in New England). In these areas, the growing season lasts only as long as there is enough moisture for plants to grow.

Soil

Plants need soil that contains adequate nutrients and organic matter. Nutrients and organic matter are added to soil when plant litter and dead organisms decompose. In cold climates, decomposition occurs very slowly. As a result, soil in cold climates is thin and poor in nutrients. Soil is also thin and poor in hot, wet climates because the heat and humidity cause such rapid decomposition that little organic matter accumulates in the soil. The frequent rains also leach nutrients from the soil. Thin, poor soil is shown in the left drawing of **Figure 5**. The right drawing shows thick, rich soil. This type of soil is generally found in temperate climates and is best for most plants.

Biome Biodiversity and Adaptations

Because plants are the most important producers in terrestrial biomes, anything that affects their growth also influences the number and variety of other organisms that can be supported in a biome. Therefore, climate has a major impact on the biodiversity of biomes.

Biodiversity

Biodiversity refers to the number of different species of organisms in a biome (or ecosystem or other ecological unit). Biodiversity is usually greater in warmer biomes. Therefore, biodiversity generally decreases

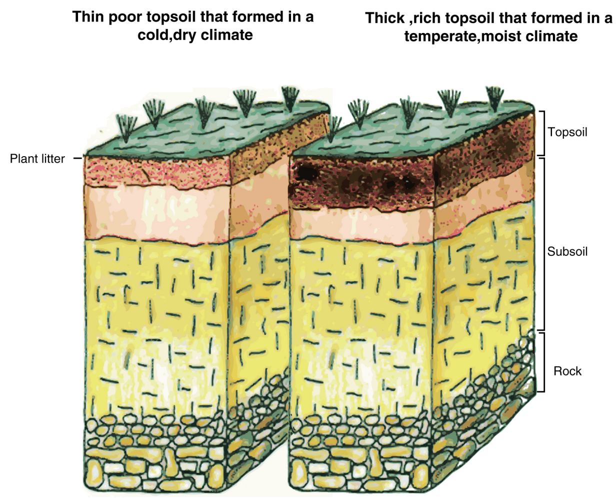


Figure 7.5: The soil on the left has a thin layer of topsoil, the part of soil where most plant roots obtain moisture and nutrients. The topsoil is light in color, which means that it is poor in nutrients and organic matter. The soil on the right has a thicker layer of topsoil. Its dark color indicates that the topsoil is rich in nutrients and organic matter.

from the equator to the poles. Biodiversity is usually greater in wetter biomes, as well. Remember the desert and rainforest pictured in **Figure 1**? The biodiversity of these two biomes is vastly different. Both biomes have warm climates, but the desert is very dry, and the rainforest is very wet. The desert has very few organisms, so it has low biodiversity. Some parts of the desert may have no organisms, and therefore zero biodiversity. In contrast, the rainforest has the highest biodiversity of any biome on Earth.


A discussion of biodiversity (**6a**) is available at http://www.youtube.com/watch?v=vGxJArebKoc (6:12).

Figure 7.6: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/173

Adaptations

Plants, animals, and other organisms evolve adaptations to suit them to the abiotic factors in their biome. Abiotic factors to which they adapt include temperature, moisture, growing season, and soil. This is why the same type of biome in different parts of the world has organisms with similar adaptations. For example, biomes with dry climates worldwide have plants with similar adaptations to aridity, such as special tissues for storing water (see **Figure 6**).

Figure 7.7: (left) The large hollow leaves of an African aloe plant store water and help the plant survive in its arid biome. (right) Cacti like these are found in arid biomes of North America. They store water in their thick, barrel-like stems.

In biomes with a severe cold or dry season, plants may become dormant during that season of the year. In dormant plants, cellular activities temporarily slow down, so the plants need less sunlight and water. For example, many trees shed their leaves and become dormant during very cold or dry seasons. Animals in very cold or dry biomes also must adapt to these abiotic factors. For example, adaptations to cold include fur or fat, which insulates the body and helps retain body heat.

Changes in ecosystems (**6b**) are discussed at http://www.youtube.com/watch?v=jHWgWxDWhsA (7:47) and http://www.youtube.com/watch?v=5qblwORXwrg (2:26).

Figure 7.8: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/174

Figure 7.9: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/175

7.3 Terrestrial Biomes

Terrestrial biomes include all land areas on Earth where organisms live. The major biomes cover large regions and are found on more than one continent. They are generally classified on the basis of climatic factors and the types of plants that are the primary producers.

Classification of Terrestrial Biomes

Scientists have created several different systems for classifying terrestrial biomes. Biomes in most classification systems include tundra, boreal forest, temperate forest, temperate grassland, chaparral, tropical forest, tropical grassland, and desert. The worldwide distribution of these biomes is shown in **Figure 1**.

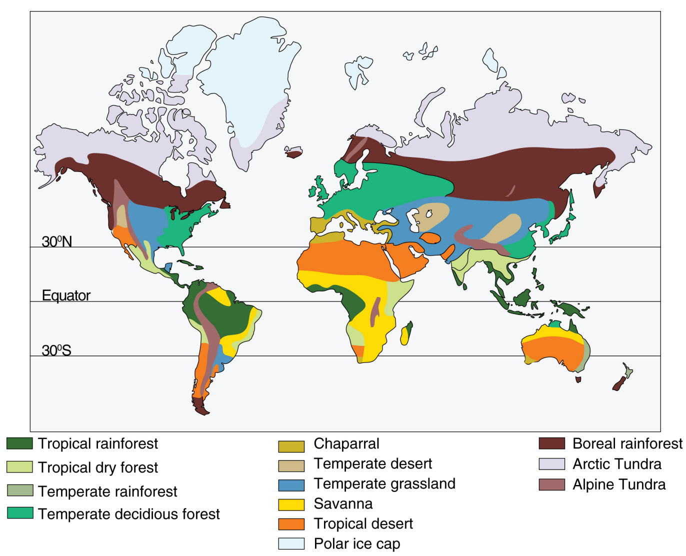


Figure 7.10: Distribution of Earth

The distribution of biomes shown in **Figure 1** reflects global patterns of temperature and moisture. It also reflects conditions in earlier times. Many areas have been disturbed by human actions, some more so than others. For example, most tundra biomes have been changed very little by human actions, but many forests have been completely cleared. Some biomes, including tropical rainforests, cannot be replaced once they have been destroyed. **Figure 2** summarizes important features of most of the biomes shown in **Figure 1**. Refer to both figures as you read about these terrestrial biomes throughout this lesson.

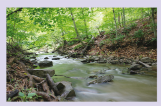
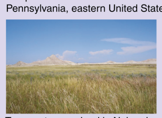
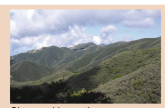
Biome: Other Name(s)	Type of Climate, Growing Season, Soil Quality	Biodiversity, Common Plants, Common Animals
Tundra: Artic tundra (high latitudes) Alpine tundra (high altitudes)	*Type of climate*: arctic, arid *Growing season:* very short *Soil quality:* Very poor	 Alpine tundra in the Alps Mountains of Switzerland in Europe  Arctic tundra on the northern coast of Alaska in the United States *Biodiversity:* very low *Plants*: mosses, grasses, and lichens; few herbaceous plants; no trees *Animals:* insects; birds (summer only); no amphibians or reptiles; mammals such as rodents, arctic hares, arctic foxes, polar bears; caribou (summer only); mountain goats and chinchillas (alpine tundra only)
Boreal Forest: Taiga Northern conifer forest	*Climate:* subarctic, semi-arid *Growing season:* short *Soil quality:* Poor	*Biodiversity:* low *Plants:* conifers such as cedar, spruce, pine, and fir; mosses and lichens *Animals:* insects; birds (mainly in summer); no amphibians or reptiles; mammals such as rodents, rabbits, minks, raccoons, bears, and moose; caribou (winter only)  Boreal forest in central (inland) Alaska, United States
Temperate Deciduous Forest: Temperate hardwood forest Temperate broadleaf forest	*Climate:* temperate, semi-humid *Growing season:* medium *Soil quality:* good *Climate:* temperate, semi-arid *Growing season:* medium *Soil quality:* excellent	 Temperate deciduous forest in Pennsylvania, eastern United States *Biodiversity*: high *Plants*: broadleaf deciduous trees such as beech, maple, oak, and hickory; ferns, mosses, and shrubs; many herbaceous plants *Animals*: insects, amphibians, reptiles, and birds; mammals such as mice, chipmunks, squirrels, raccoons, foxes, deer, black bears, bobcats, and wolves  Temperate grassland in Nebraska, midwestern United States *Biodiversity*: medium–high *Plants*: grasses; other herbaceous plants; no trees *Animals*: invertebrates such as worms and insects; amphibians, reptiles, and birds; mammals such as mice, prairie dogs, rabbits, foxes, wolves, coyotes, bison, and antelope; kangaroo (only in Australia)
Chaparral Mediterranean scrub forest	*Climate:* temperate, semi-arid *Growing season:* medium *Soil quality:* poor	*Biodiversity*: low–medium *Plants:* shrubs and small trees such as scrub oak and scrub pine *Animals:* insects, reptiles, and birds; mammals such as rodents and deer  Chaparral in southern California, United States
Desert	*Climate:* temperate or tropical, arid *Growing season:* varies *Soil quality:* very poor	*Biodiversity:* none–low *Plants:* plants adapted to dryness, such as cacti, sage-brush, and mesquite; virtually no plants if extremely arid *Animals*: insects, reptiles, and birds; mammals such as rodents and coyotes  Desert in southern California, United States
Tropical Rainforest	*Climate:* tropical, humid *Growing season:* year-round *Soil quality:* excellent	*Biodiversity*: very high *Plants*: tall flowering, broadleaf evergreen trees; vines and epiphytes; few plants on forest floor *Animals:* insects, amphibians, reptiles, and birds; mammals such as monkeys, sloths, leopards, jaguars, pigs, and tigers  Tropical rainforest in Ecuador, South America
Tropical Grassland Savanna	*Climate*: tropical, semi-arid *Growing season:* year-round *Soil quality:* poor	*Biodiversity*: low–medium *Plants*: grasses; scattered clumps of trees *Animals:* insects, reptiles, and birds; mammals such as zebras, giraffes, antelopes, lions, cheetahs, and hyenas  Elephant browsing on the leaves of an acacia tree in savanna in Kenya, eastern Africa

Figure 7.11: These biomes are described more fully in the text. Refer to

Arctic and Subarctic Biomes

Artic and subarctic biomes are found near the north and south poles or at high altitudes in other climate zones. The biomes include tundra and boreal forests. Both have cold, dry climates and poor soil. They can support only limited plant growth and have low biodiversity.

Tundra

Tundra is an arctic biome where it is too cold for trees to grow. Outside of the polar ice caps, tundra has the coldest temperatures on Earth. There are two types of tundra: arctic tundra, which is also found in Antarctica, and alpine tundra, which is found only at high altitudes.

- **Arctic tundra** occurs north of the arctic circle and south of the antarctic circle. It covers much of Alaska and vast areas of northern Canada and Russia. It is also found along the northern coast of Antarctica.
- **Alpine tundra** occurs in mountains around the world at any latitude, but only above the tree line. The **tree line** is the edge of the zone at which trees are able to survive. Alpine tundra is found in the Rocky Mountains in the United States and in several other mountain ranges around the world.

Both types of tundra receive very low precipitation, but little of it evaporates because of the cold. Arctic tundra has **permafrost,** which is soil that is frozen year-round. The top layer of soil thaws in the summer, but deeper layers do not. As a result, water cannot soak into the ground. This leaves the soil soggy and creates many bogs, lakes, and streams. Alpine tundra does not have permafrost, except at very high altitudes. Therefore, alpine tundra soil tends to be dry rather than soggy.

Global warming poses a serious threat to Arctic tundra biomes because it is causing the permafrost to melt. When permafrost melts, it not only changes the tundra. It also releases large amounts of methane and carbon dioxide into the atmosphere. Both are greenhouse gases, which contribute to greater global warming.

The most common vegetation in tundra is mosses and lichens. They can grow in very little soil and become dormant during the winter. Tundra is too cold for amphibians or reptiles, which cannot regulate their own body heat. Insects such as mosquitoes can survive the winter as pupae and are very numerous in summer. In addition, many species of birds and large herds of caribou migrate to arctic tundra each summer. However, few birds and mammals live there year-round. Those that remain have adapted to the extreme cold. Polar bears are an example. They have very thick fur to insulate them from the cold. In alpine tundra, animals must adapt to rugged terrain as well as to cold. Alpine animals include mountain goats, which not only have wool to keep them warm but are also sure-footed and agile.

Boreal Forests

A **boreal forest** is a subarctic biome covered with conifers. Conifers are cone-bearing, needle-leaved evergreen trees such as spruces. Boreal forests are found only in the northern hemisphere. They occur just south of the arctic circle in Alaska, Canada, northern Europe, and Russia (where they are called taiga). They also occur in extreme northern regions of Minnesota, New York State, New Hampshire, and Maine.

Boreal forests have harsh continental climates, with very cold winters and relatively warm summers. The growing season is also short. Precipitation is quite low, but there is little evaporation. Most of the precipitation falls in the summer when plants are growing, so there is enough moisture for dense plant growth. A thick carpet of evergreen needles on the forest floor causes the soil to be too acidic for most other plants.

Conifers have adapted to the difficult conditions in several ways. They have shallow roots that suit them for the thin soil. They have needles instead of leaves, which reduce water loss during the long, dry winters. The needles are also very dark green in color, which maximizes absorption of sunlight for photosynthesis. Although boreal forests are dense with conifers, there are only a few different species of trees. Vegetation on the forest floor consists mostly of mosses and lichens. Animals found in boreal forests include insects, birds, and mammals such as rabbits, foxes, and brown bears. Caribou also spend their winters there. Like tundra, the boreal forest is too cold for amphibians or reptiles.

Temperate Biomes

Temperate biomes cover most of the continental United States and Europe. They also cover large parts of Asia. Types of temperate biomes include forests, grasslands, and chaparral.

There are two types of **temperate forests**: temperate deciduous forests and temperate rainforests. Both types have a temperate climate and good soil. A temperate climate is a moderate climate that is neither extremely hot nor extremely cold. A temperate climate can be either continental or coastal. Continental temperate climates are found inland, and they tend to have cold winters, hot summers, and moderate precipitation. Coastal temperate climates are found near the ocean, and they tend to have mild winters, cool summers, and high precipitation.

- **Temperate deciduous forests** are found in areas with continental temperate climates, such as the eastern United States and Canada and throughout much of Europe. These forests consist mainly of deciduous trees, such as maples and oaks, which lose their leaves in the fall. There are many other species of plants as well. Animals include insects, amphibians, reptiles, and birds. Mammals are also common, including rabbits and wolves.
- **Temperate rainforests** are found in areas with coastal temperate climates, such as the northwestern coast of North America and certain coastal regions of other continents. These forests consist mainly of evergreen trees, such as hemlocks and firs. Mosses, lichens, and ferns grow on the forest floor. There are also many epiphytic plants. Animals include insects, amphibians, reptiles, and birds. There are also many mammals, such as squirrels and deer.

> **Epiphytes** are plants that grow on other plants. They use the other plants for support, not nutrients, and generally do not harm the plants they grow on. They grow high in the branches of trees where there is more sunlight available for photosynthesis.

Temperate grasslands are temperate biomes that consist mainly of grasses. They are found in the mid-western region of North America and in inland areas of most other continents. The climate is continental, and precipitation is relatively low. However, the majority of the precipitation falls during the growing season when plants need it the most.

Biomes are often referred to by local names. For example, a temperate grassland biome is known as prairie in North America, outback in Australia, pampa in South America, and steppe in central Asia. Can you find each of these temperate grasslands on the map in **Figure 1**?

The soil of temperate grasslands is the richest, deepest soil on Earth. It is densely covered with thick grasses that decompose to add large amounts of organic matter and nutrients to the soil. Grasses also have thick mats of roots that hold the soil in place and prevent erosion. The low rainfall does not leach many nutrients from the soil, but it does lead to frequent fires. The fires help prevent woody vegetation from moving in if a grassland is disturbed. This is because grasses can grow back after a fire, whereas most woody plants cannot.

The rich, deep soil supports high productivity. This is why the temperate grassland of the US midwest is known as the *Breadbasket of America.* Grass plants are closely spaced and can support many herbivore consumers. These range from grasshoppers to deer. Many worms and other invertebrates (animals without a backbone) consume organic matter in the soil. Grassland animals also include carnivores such as foxes and coyotes.

Chaparral is a shrub forest biome dominated by densely-growing evergreen shrubs or small trees, such as scrub oak. There are few other species of plants. Chaparral is found mainly in central and southern California and around the Mediterranean Sea. The climate, called a Mediterranean climate, has mild wet winters and hot dry summers. Fires are frequent because of the summer dryness, and the soil is relatively poor.

The majority of chaparral trees and plants are adapted to the dry summers. For example:

- Trees are short, which reduces their need for water.
- Many plants are dormant during the dry season, which also reduces water needs.
- The leaves of some plants have waxy coatings, which reduce water loss.

Most chaparral plants are adapted to frequent fires, as well. For example:

- Many plants can grow back quickly from the roots after burning to the ground.
- Some plants produce seeds that need fire in order to germinate.
- Many plants have thick underground stems that can survive fires.

The densely growing trees make it difficult for very large animals to penetrate the chaparral, so most chaparral animals are small. They include insects, birds, reptiles, and rodents. The largest animals are deer, which browse on the leaves of chaparral trees.

Deserts

A **desert** is a biome that receives no more than 25 centimeters (10 inches) of precipitation per year. Deserts are found in both temperate and tropical areas. The largest deserts are found at about 30° north or south latitude due to the dry air masses over these latitudes. Deserts also occur in rain shadows. A rain shadow is a dry region on the leeward side of a mountain range (see Lesson 16.1). Examples of rain shadow deserts include Death Valley and the Mojave Desert, both partly in California. The dry air in deserts leads to extreme temperature variations from day to night. Without water vapor in the air, there are no clouds to block sunlight during the day or hold in heat at night.

Desert soil is usually very poor. They tend to be sandy or rocky and lack organic content. Because of the low precipitation, minerals are not leached out and may become too concentrated for plants to tolerate. Plant cover is very sparse, so most of the soil is exposed and easily eroded by wind. The occasional rain tends to be brief but heavy, causing runoff and more erosion.

Most desert plants have evolved adaptations to the extreme dryness. For example:

- Many plants have special water-storing tissues in leaves, stems, or roots.
- Some plants have very long taproots that can reach down to the water table.
- Some plants have wide-spreading roots that can absorb water over a large area.
- Plants may have small, spiny leaves that help reduce water loss.

Most desert animals have adaptations to the extreme heat and bright sunlight. For example:

- Many small animals stay underground in burrows during the day and come out only at night.
- Most animals that are active in daytime spend as much time as possible in the shade of rocks or plants.
- Some animals have very large ears or other appendages, which help them lose heat to the environment, keeping them cooler.
- Many animals are light in color, which helps them reflect sunlight and stay cooler.

Tropical Biomes

Tropical biomes receive more sunlight than any other biomes on Earth. They also have high temperatures year-round. In addition to deserts, tropical biomes include forests and grasslands.

Tropical Forests

There are two types of tropical forests: tropical rainforests and tropical dry forests. Both occur near the equator, so they have plenty of sunlight and warmth year-round. However, they differ in the amount and timing of the precipitation they receive.

- **Tropical rainforests** receive more precipitation than any other biome. They are found near the equator in Central and South America and Africa. The soil is thin and poor, partly because the lush plant growth uses up nutrients before they can accumulate in the soil. Biodiversity of animals as well as plants is greater than in all other biomes combined. Most plants are tall, broadleaf evergreen trees. They form a dense canopy over the forest, so little sunlight reaches the forest floor. The many vines and epiphytes reach sunlight by growing on trees. Numerous animal species also live in trees, including monkeys, sloths, and leopards.
- **Tropical dry forests** occur in tropical areas where most of the precipitation falls during a single wet season. As a result, there is a pronounced dry season. Tropical dry forests are found in parts of Central and South America, Africa, and India. Trees and other plants are widely spaced because there is not enough water for denser growth. The plants also have adaptations to help them cope with seasonal drought. For example, many go dormant during the dry season, which reduces their need for water. Animals that live in tropical dry forests include arboreal animals such as monkeys and ground-dwelling animals such as rodents.

Tropical Grasslands

Tropical grasslands are tropical biomes with relatively low rainfall where the primary producers are grasses. Tropical grasslands are found mainly in Africa, where they are called savannas. They have high temperatures year-round, but relatively low precipitation. Moreover, most of the precipitation falls during a single wet season, leaving the rest of the year very dry. The soil is also poor.

In addition to grasses, there are scattered clumps of trees in most tropical grasslands. The trees are drought-adapted species such as acacia, which have narrow leaves that reduce water loss. Acacia trees also have thorns that discourage browsing by herbivores. Africa savannas are well known for their huge herds of herbivores, including zebra, giraffe, and wildebeest. They are also well known for their large carnivores—such as lions, cheetahs, and hyenas—that prey on the herbivores.

7.4 Aquatic Biomes

Terrestrial organisms are generally limited by temperature and moisture. Therefore, terrestrial biomes are defined in terms of these abiotic factors. In contrast, most organisms that live in the water do not have to deal with extremes of temperature or moisture. Instead, their main limiting factors are the availability of sunlight and the concentration of dissolved nutrients in the water.

What Are Aquatic Biomes?

Aquatic biomes are biomes found in water. Water covers 70 percent of Earth's surface, so aquatic biomes are a major component of the biosphere. However, they have less total biomass than terrestrial biomes. Aquatic biomes can occur in either salt water or freshwater. About 98 percent of Earth's water is salty, and only 2 percent is fresh. The primary saltwater biome is the ocean. Major freshwater biomes include lakes and rivers.

Aquatic Zones

In large bodies of standing water (including the ocean and lakes), the water can be divided into zones based on the amount of sunlight it receives. There is enough sunlight for photosynthesis only in - at most - the top 200 meters of water. Water down to this depth is called the **photic zone**. Deeper water, where too little sunlight penetrates for photosynthesis, is called the **aphotic zone.**

Surface water dissolves oxygen from the air, so there is generally plenty of oxygen in the photic zone to support organisms. Water near shore usually contains more dissolved nutrients than water farther from the shore. This is because most dissolved nutrients enter a body of water from land, carried by runoff or rivers that empty into the body of water. When aquatic organisms die, they sink to the bottom, where decomposers release the nutrients they contain. As a result, deep water may contain more nutrients than surface water.

`Deep ocean water may be forced to the surface by currents in a process called '''upwelling.''' When this happens, dissolved nutrients are brought to the surface from the deep ocean. The nutrients can support large populations of producers and consumers, including many species of fish. As a result, areas of upwelling are important for commercial fishing.`With these variations in sunlight, oxygen, and nutrients, different parts of the ocean or a lake have different types and numbers of organisms. Therefore, life in a lake or the ocean is generally divided into zones. The zones correlate mainly with the amount of sunlight and nutrients available to producers. **Figure 1** shows ocean zones. Lakes have similar zones.

- The **littoral zone** is the shallow water near the shore. In the ocean, the littoral zone is also called the intertidal zone.
- The **pelagic zone** is the main body of open water farther out from shore. It is divided into additional zones based on water depth. In the ocean, the part of the pelagic zone over the continental shelf is called the **neritic zone,** and the rest of the pelagic zone is called the **oceanic zone.**
- The **benthic zone** is the bottom surface of a body of water. In the ocean, the benthic zone is divided into additional zones based on depth below sea level.

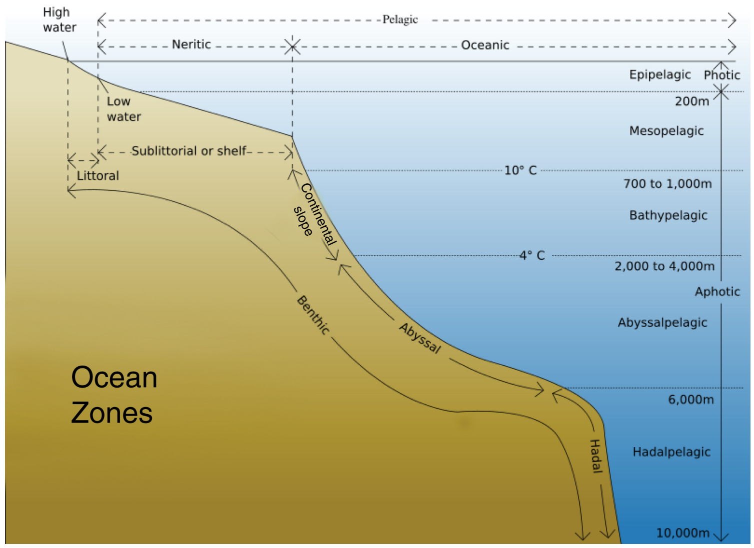


Figure 7.12: The ocean is divided into many different zones, depending on distance from shore and depth of water. The pelagic zone is divided into neritic and oceanic zones based on distance from shore. Into what additional zones is the pelagic zone divided on the basis of water depth? What additional zones make up the benthic zone?

Aquatic Organisms

Aquatic organisms are classified into three basic categories: plankton, nekton, and benthos. Organisms in these three categories vary in where they live and how they move.

- **Plankton** are aquatic organisms that live in the water itself and cannot propel themselves through water. They include both phytoplankton and zooplankton. Phytoplankton are bacteria and algae that use sunlight to make food by photosynthesis. Zooplankton are tiny animals that feed on phytoplankton.
- **Nekton** are aquatic animals that live in the water and can propel themselves by swimming or other means. Nekton include invertebrates such as shrimp and vertebrates such as fish.
- **Benthos** are aquatic organisms that live on the surface below a body of water. They live in or on the sediments at the bottom. Benthos include sponges, clams, and sea stars (see **Figure 2**).

Marine Biomes

Marine biomes are aquatic biomes found in the salt water of the ocean. Major marine biomes are neritic, oceanic, and benthic biomes. Other marine biomes include intertidal zones, estuaries, and coral reefs.

Neritic Biomes

Neritic biomes occur in ocean water over the continental shelf (see **Figure 1**). They extend from the low-tide water line to the edge of the continental shelf. The water here is shallow, so there is enough sunlight for photosynthesis. The water is also rich in nutrients, which are washed into the water from the nearby land. Because of these favorable conditions, large populations of phytoplankton live in neritic biomes. They produce enough food to support many other organisms, including both zooplankton and

Figure 7.13: This sea star, or starfish, is an example of a benthic organism. The tiny white projections on the bottom surface of the sea star allow it anchor to, or slowly crawl over, the bottom surface of the ocean.

nekton. As a result, neritic biomes have relatively great biomass and biodiversity. They are occupied by many species of invertebrates and fish. In fact, most of the world's major saltwater fishing areas are in neritic biomes.

Oceanic Biomes

Oceanic biomes occur in the open ocean beyond the continental shelf. There are lower concentrations of dissolved nutrients away from shore, so the oceanic zone has a lower density of organisms than the neritic zone. The oceanic zone is divided into additional zones based on water depth (see **Figure 1**).

- The **epipelagic zone** is the top 200 meters of water, or the depth to which enough sunlight can penetrate for photosynthesis. Most open ocean organisms are concentrated in this zone, including both plankton and nekton.
- The **mesopelagic zone** is between 200 and 1,000 meters below sea level. Some sunlight penetrates to this depth but not enough for photosynthesis. Organisms in this zone consume food drifting down from the epipelagic zone, or they prey upon other organisms in their own zone. Some organisms are detrivores, which consume dead organisms and organic debris that also drift down through the water.
- The **bathypelagic zone** is between 1,000 and 4,000 meters below sea level. No sunlight penetrates below 1,000 meters, so this zone is completely dark. Most organisms in this zone either consume dead organisms drifting down from above or prey upon other animals in their own zone. There are fewer organisms and less biomass here than in higher zones. Some animals are bioluminescent, which means they can give off light (see **Figure 3**). This is an adaptation to the total darkness.
- The **abyssopelagic zone** is between 4,000 and 6,000 meters below sea level. The **hadopelagic zone** is found in the water of deep ocean trenches below 6,000 meters. Both of these zones are similar to the bathypelagic zone in being completely dark. They have even lower biomass and species diversity.

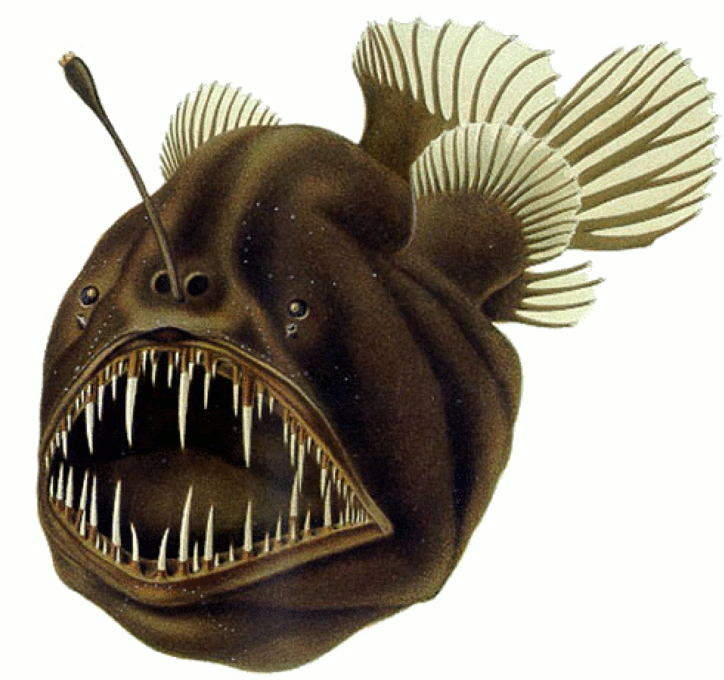


Figure 7.14: The anglerfish lives in the bathypelagic zone. The rod-like structure protruding from the anglerfish

Benthic Biomes

Benthic biomes occur on the bottom of the ocean where benthos live. Some benthos, including sponges, are sessile, or unable to move, and live attached to the ocean floor. Other benthos, including clams, burrow into sediments on the ocean floor. The benthic zone can be divided into additional zones based on how far below sea level the ocean floor is (see **Figure 1**).

- The **sublittoral zone** is the part of the ocean floor that makes up the continental shelf near the shoreline. The water is shallow enough for sunlight to penetrate down to the ocean floor. Therefore, photosynthetic producers such as seaweed can grow on the ocean floor in this zone. The littoral zone is rich in marine life.
- The **bathyal zone** is the part of the ocean floor that makes up the continental slope. It ranges from about 1,000 to 4,000 meters below sea level. The bathyal zone contains no producers because it is too far below the surface for sunlight to penetrate. Although consumers and decomposers live in this zone, there are fewer organisms here than in the sublittoral zone.
- The **abyssal zone** is the part of the ocean floor in the deep open ocean. It varies from about 4,000 to 6,000 meters below sea level. Organisms that live on the ocean floor in this zone must be able to withstand extreme water pressure, continuous cold, and scarcity of nutrients. Many of the organisms sift through sediments on the ocean floor for food or dead organisms.
- The **hadal zone** is the ocean floor below 6,000 meters in deep ocean trenches. The only places where organisms are known to live in this zone are at hydrothermal vents, where invertebrates such as tubeworms and clams are found. They depend on microscopic archaea organisms for food. These tiny chemosynthetic producers obtain energy from chemicals leaving the vents (see the *Principles of Ecology* chapter).

Intertidal Zone

The **intertidal zone** is a narrow strip along the coastline that falls between high- and low-tide water lines. It is also called the littoral zone (see **Figure 1**). A dominant feature of this zone is the regular movement of the tides in and out. In most areas, this occurs twice a day. Due to the tides, this zone alternates between being under water at high tide and being exposed to the air at low tide. An intertidal zone is pictured in **Figure 4**.

Figure 7.15: These pictures show the Bay of Fundy off the northeastern coast of Maine in North America. The picture on the left shows the bay at high tide, and the picture on the right shows the bay at low tide. The area covered by water at high tide and exposed to air at low tide is the intertidal zone.

The high tide repeatedly brings in coastal water with its rich load of dissolved nutrients. There is also plenty of sunlight for photosynthesis. In addition, the shallow water keeps large predators, such as whales and big fish, out of the intertidal zone. As a result, the intertidal zone has a high density of living things. Seaweeds and algae are numerous, and they support many consumer species, either directly or indirectly, including barnacles, sea stars, and crabs.

Other conditions in the intertidal zone are less favorable. For example, there are frequent shifts from a water to an air environment. There are also repeated changes in temperature and salinity (salt concentration). These changing conditions pose serious challenges to marine organisms. The moving water poses yet another challenge. Organisms must have some way to prevent being washed out to sea with the tides. Barnacles, like those in **Figure 5**, cement themselves to rocks. Seaweeds have rootlike structures, called holdfasts, which anchor them to rocks. Crabs burrow underground to avoid being washed out with the tides.

Other Marine Biomes

The intertidal zone has high biodiversity. However, it is not the marine biome with the highest biodiversity. That distinction goes to estuaries and coral reefs. They have the highest biodiversity of all marine biomes.

- An **estuary** is a bay where a river empties into the ocean. It is usually semi-enclosed, making it a protected environment. The water is rich in dissolved nutrients from the river and shallow enough

Figure 7.16: Barnacles secrete a cement-like substance that anchors them to rocks.

for sunlight to penetrate for photosynthesis. As a result, estuaries are full of marine life. **Figure 6** shows an estuary on the California coast near San Francisco.

Figure 7.17: This satellite photo shows the San Francisco Estuary on the California coast. This is the largest estuary on the lower west coast of North America. Two rivers, the Sacramento and the San Joaquin, flow into the estuary (upper right corner of photo). The estuary is almost completely enclosed by land but still connected to the ocean.

- A **coral reef** is an underwater limestone structure produced by tiny invertebrate animals called corals. Coral reefs are found only in shallow, tropical ocean water. Corals secrete calcium carbonate (limestone) to form an external skeleton. Corals live in colonies, and the skeletal material gradually accumulates to form a reef. Coral reefs are rich with marine organisms, including more than 4,000 species of tropical fish. **Figure 7** shows a coral reef in the Hawaiian Islands.

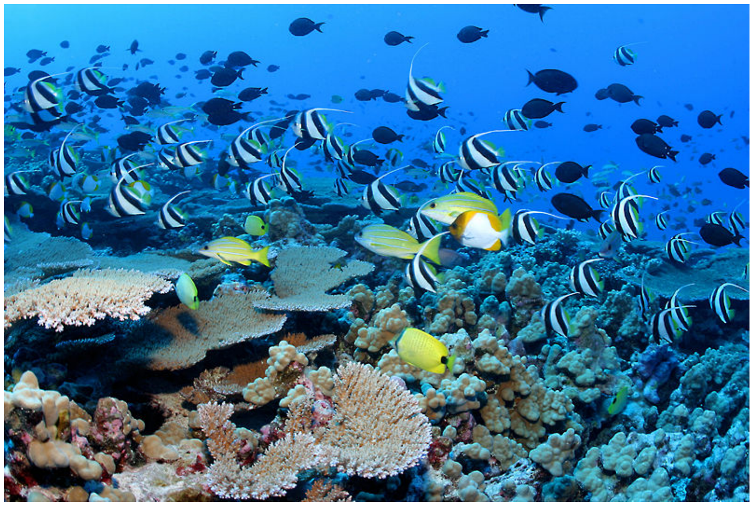


Figure 7.18: Colorful fish swim in warm, shallow ocean water near a coral reef off the Hawaiian Islands.

Freshwater Biomes

Freshwater biomes occur in water that contains little or no salt. Freshwater biomes include standing water and running water biomes.

Standing Freshwater Biomes

Standing freshwater biomes include ponds and lakes. Ponds are generally smaller than lakes and shallow enough for sunlight to reach all the way to the bottom. In lakes, at least some of the water is too deep for sunlight to penetrate. As a result, like the ocean, lakes can be divided into zones based on availability of sunlight for producers.

- The littoral zone is the water closest to shore. The water in the littoral zone is generally shallow enough for sunlight to penetrate, allowing photosynthesis. Producers in this zone include both phytoplankton and plants that float in the water. They provide food, oxygen, and habitat to other aquatic organisms. The littoral zone generally has high productivity and high biodiversity.
- The **limnetic zone** is the top layer of lake water away from shore. This zone covers much of the lake's surface, but it is only as deep as sunlight can penetrate. This is a maximum of 200 meters. If the water is muddy or cloudy, sunlight cannot penetrate as deeply. Photosynthesis occurs in this zone, and the primary producers are phytoplankton, which float suspended in the water. Zooplankton and nekton are also found in this zone. The limnetic zone is generally lower in productivity and biodiversity than the littoral zone.
- The **profundal zone** is the deep water near the bottom of a lake where no sunlight penetrates. Photosynthesis cannot take place, so there are no producers in this zone. Consumers eat food that drifts down from above, or they eat other organisms in the profundal zone. Decomposers break down dead organisms that drift down through the water. This zone has low biodiversity.

- The benthic zone is the bottom of a lake. Near the shore, where water is shallow, the bottom of the lake receives sunlight, and plants can grow in sediments there. Organisms such as crayfish, snails, and insects also live in and around the plants near shore. The plants provide shelter from predatory fish as well as food and oxygen. In deeper water, where the bottom of the lake is completely dark, there are no producers. Most organisms that live here are decomposers.

The surface water of a lake is heated by sunlight and becomes warmer than water near the bottom. Because warm water is less dense that cold water, it remains on the surface. When dead organisms sink to the bottom of a lake, they are broken down by decomposers that release the nutrients from the dead organism. As a result, nutrients accumulate at the lake's bottom. In spring and fall in temperate climates, the surface water of a lake reaches the same temperature as the deeper water. This gives the different water layers the same density, allowing them to intermix. This process, called **turnover,** brings nutrients from the bottom of the lake to the surface, where producers can use them.

Lakes can be categorized on the basis of their overall nutrient levels, as shown in **Table 1**. Oligotrophic lakes have low nutrient levels, so they also have low productivity. With few producers (or other aquatic organisms), the water remains clear and little oxygen is used up to support life. Biodiversity is low.

Table 7.1: **Trophic Classification of Freshwater Lakes**

Type of Lake	Nutrient Level	Productivity	Clarity of Water	Oxygen Level
Oligotrophic	Low	Low	High	High
Mesotrophic	Medium	Medium	Medium	Medium
Eutrophic	High	High	Low	Low
Hypertrophic	Very high	Very high	Very low	Very low

Acid rain is another cause of low productivity in lakes. Acid rain falling into a lake causes the lake water to become too acidic for many species to tolerate. This results in a decline in the number and diversity of lake organisms. This has happened to many lakes throughout the northeastern United States. The water in the lakes is very clear because it is virtually devoid of life.Lakes with high nutrient levels have higher productivity, cloudier water, lower oxygen levels, and higher biomass and biodiversity. Very high nutrient levels in lakes are generally caused by contamination with fertilizer or sewage. The high concentration of nutrients may cause a massive increase in phytoplankton, called a phytoplankton bloom (see **Figure 8**). The bloom blocks sunlight from submerged plants and other producers and negatively impacts most organisms in the lake.

Running Freshwater Biomes

Running freshwater biomes include streams and rivers. Streams are generally smaller than rivers. Streams may start with surface runoff, snowmelt from a glacier, or water seeping out of the ground from a spring. If the land is not flat, the water runs downhill. The water joins other streams and then rivers as it flows over the land. Eventually, the water empties into a pond, lake, or the ocean.

Some species living in rivers that empty into the ocean may live in freshwater during some stages of their life cycle and in salt water during other stages. For example, salmon are born and develop in freshwater rivers and then move downstream to the ocean, where they live as adults. In contrast, some eels are born and develop in the ocean and then move into freshwater rivers to live as adults.Compared with standing water, running water is better able to dissolve oxygen needed by producers and other aquatic organisms. When a river rushes over

Figure 7.19: The phytoplankton bloom on this lake blocks most sunlight from penetrating below the surface, creating a condition detrimental to many other aquatic organisms.

a waterfall, like the one in **Figure 9**, most of the water is exposed to the air, allowing it to dissolve a great deal of oxygen. Flowing water also provides a continuous supply of nutrients. Some nutrients come from the decomposition of dead aquatic organisms. Other nutrients come from the decomposition of dead terrestrial organisms, and other organic debris such as leaves, that fall into the water.

Figure 7.20: Flowing water forms a waterfall on the South Yuba River in Nevada County, California. As the water falls through the air, it dissolves oxygen needed by aquatic organisms.

Algae are the main producers in running freshwater biomes. If water flows slowly, algae can float suspended in the water, and huge populations may form, like the phytoplankton bloom in **Figure 8** above. If water flows rapidly, algae must attach themselves to rocks or plants to avoid being washed away and generally cannot form very large populations.

Plants are also important producers in most running water biomes. Some plants, such as mosses, cling to rocks. Other plants, such as duckweed, float in the water. If nutrient levels are high, floating plants may form a thick mat on the surface of the water, like the one shown in **Figure 10** (left photo). Still other plants grow in sediments on the bottoms of streams and rivers. Many of these plants—like the cattails in **Figure 10** (right photo)—have long narrow leaves that offer little resistance to the current. In addition to serving as a food source, plants in running water provide aquatic animals with protection from the current and places to hide from predators.

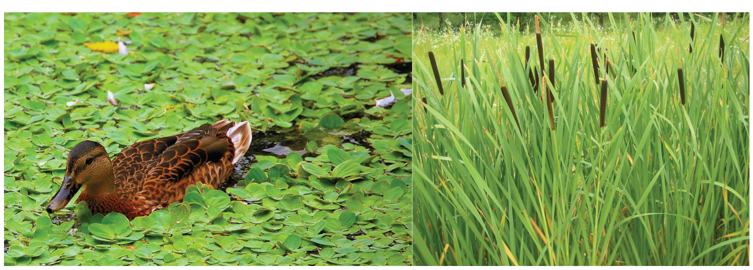


Figure 7.21: The picture on the left shows a thick mat of duckweed floating on a river. The picture on the right shows cattails growing in sediments at the edge of a stream bed. Notice the cattails

Consumers in running water include both invertebrate and vertebrate animals. The most common invertebrates are insects. Others include snails, clams, and crayfish. Some invertebrates live on the water surface, others float suspended in the water, and still others cling to rocks on the bottom. All rely on the current to bring them food and dissolved oxygen. The invertebrates are important consumers as well as prey to the many vertebrates in running water. Vertebrate species include fish, amphibians, reptiles, birds, and mammals. However, only fish live in the water all the time. Other vertebrates spend part of their time on land.

The movement of running water poses a challenge to aquatic organisms, which have adapted in various ways. Some organisms have hooks or threadlike filaments to anchor themselves to rocks or plants in the water. Other organisms, including fish, have fins and streamlined bodies that allow them to swim against the current.The interface between running freshwater and land is called a **riparian zone.** It includes the vegetation that grows along the edge of a river and the animals that consume or take shelter in the vegetation. Riparian zones are very important natural areas for several reasons:

- They filter pollution from surface runoff before it enters a river.
- They help keep river water clear by trapping sediments.
- They protect river banks from erosion by running water.
- They help regulate the temperature of river water by providing shade.

Wetlands

A **wetland** is an area that is saturated or covered by water for at least one season of the year. Freshwater wetlands are also called swamps, marshes, or bogs. Saltwater wetlands include estuaries, which are described earlier in this lesson. Wetland vegetation must be adapted to water-logged soil, which contains little oxygen. Freshwater wetland plants include duckweed and cattails (see **Figure 10**, above). Some wetlands also have trees. Their roots may be partly above ground to allow gas exchange with the air. Wetlands are extremely important biomes for several reasons.

- They store excess water from floods and runoff.
- They absorb some of the energy of running water and help prevent erosion.
- They remove excess nutrients from runoff before it empties into rivers or lakes.
- They provide a unique habitat that certain communities of plants need to survive.
- They provide a safe, lush habitat for many species of animals.

7.5 End of Chapter Review & Resources

Chapter Summary

A biome is a group of similar ecosystems that cover a broad area. Climate is the average weather in an area over a long period of time. Climate is the most important abiotic factor affecting the distribution of terrestrial biomes. Climate includes temperature and precipitation, and it determines growing season and soil quality. Climate is the major factor affecting the number and diversity of plants in terrestrial biomes. By affecting plants, which are the main producers, climate affects the biodiversity of terrestrial biomes. Plants and other organisms also evolve adaptations to climatic factors in their biomes, including adaptations to extreme cold and dryness. Aquatic biomes are divided into zones based on factors such as water depth and amount of sunlight available for photosynthesis. Aquatic organisms include plankton, nekton, and benthos. Marine biomes include neritic, oceanic, and benthic biomes. Intertidal zones, estuaries, and coral reefs are marine biomes with the highest biodiversity. Freshwater biomes may be standing water biomes, such as lakes, or running water biomes, such as rivers. Wetlands are biomes in which the ground is saturated or covered by water for at least part of the year. Abiotic factors such as water depth affect organisms in aquatic biomes. Organisms in all biomes are also affected by biotic factors, which include their interactions with other species.

Review Questions

1. Name three factors that help determine the climate of an ecosystem.
2. What is a rain shadow?
3. List some important factors related to climate that plants need in order to grow?
4. Explain how the quality of soil in an area is influenced by climate.
5. Why is biodiversity higher at the equator than it is near the poles?
6. Identify the two types of tundra and where they are found.
7. Name two temperate biomes and the main type of plant found in each biome.
8. In which biome are you most likely to find grasses, zebras, and lions?
9. If you were to design a well-adapted desert animal, what traits would you give it to help it survive in its desert environment?
10. Compare and contrast two types of temperate forests.
11. If the tropics receive more sunlight year-round than any other biome, why are some plants in tropical rainforests adapted to low levels of sunlight?
12. The land areas where terrestrial biomes are found cover only 30 percent of Earth's surface. The rest of the surface is covered by water. What do you think are some of the organisms that live in water biomes?
13. In a large body of standing water, what is the photic zone?
14. State why the oceanic zone has a lower concentration of nutrients than the neritic zone.
15. Why is moving water a major challenge for organisms in the littoral zone of the ocean?
16. Why does the profundal zone of a lake have no producers?
17. A new species of bioluminescent fish has been discovered in the ocean. Which oceanic zone is most likely the home of this fish? Explain your answer.
18. A developer plans to extend a golf course into a riparian biome. Outline environmental arguments you could make against this plan.
19. Compare and contrast plankton, nekton, and benthos.
20. In the deep ocean far from shore, why might you find more dissolved nutrients at the bottom than at the surface?

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Vocabulary to Know

- abyssal zone- Part of the ocean floor that is under the deep ocean.

- alpine tundra - Tundra biome that occurs in mountains around the world at any latitude, but only above the tree line.
- abyssopelagic zone - Water between 4,000 and 6,000 meters below sea level in the oceanic zone.
- aquatic biome - Biome in water.
- aphotic zone - Deep water in a lake or the ocean where too little sunlight penetrates for photosynthesis to occur.
- arctic tundra - Tundra biome that occurs north of the arctic circle and south of the antarctic circle.
- bathyal zone - Part of the ocean floor that makes up the continental slope.
- bathypelagic zone - Water between 1,000 and 4,000 meters below sea level in the oceanic zone.
- benthic biome - Marine biome that occurs on the bottom of the ocean where benthos live.
- benthic zone - Bottom surface of the ocean or a lake.
- benthos - Aquatic organisms that live on the surface below a body of water.
- biodiversity - Number of different species of organisms in a biome (or ecosystem or other unit).
- biome - Group of similar ecosystems that cover a broad area.
- boreal forest - Subarctic biome covered with conifers.
- chaparral - Temperate biome with a Mediterranean climate that consists mainly of densely-growing evergreen shrubs such as scrub oak.
- climate - Average weather in an area over a long period of time.
- coral reef - Underwater limestone structure formed by tiny invertebrate animals called corals.
- desert - Temperate or tropical biome that receives no more than 25 centimeters of precipitation per year.
- epipelagic zone - Top 200 meters of water in the oceanic zone.
- epiphyte - Type of plant that grows on other plants for support.
- estuary - Bay where a river empties into the ocean.
- freshwater biome - Biome such as a lake or river that has water with little or no salt.
- growing season - Period of time each year when it is warm enough for plants to grow.
- hadal zone - Part of the ocean floor that is in deep ocean trenches.
- hadopelagic zone - Water of deep ocean trenches below 6,000 meters in the oceanic zone.
- intertidal zone - Narrow strip along the coastline of the ocean that falls between high- and low-tide water lines.
- limnetic zone - Top layer of deep water in a lake, down to the depth that sunlight penetrates.
- littoral zone - Shallow water near the shore of a lake or the ocean.
- marine biome - Aquatic biome found in the salt water of the ocean.
- mesopelagic zone - Water between 200 and 1,000 meters below sea level in the oceanic zone.
- nekton - Aquatic animals that live in the water itself and can propel themselves by swimming or other means.
- neritic biome - Marine biome that occurs in ocean water over the continental shelf.
- neritic zone - Part of the pelagic zone over the continental shelf.
- oceanic biome - Marine biome that occurs in ocean water beyond the continental shelf.
- oceanic zone - Part of the pelagic zone beyond the continental shelf.
- permafrost - Frozen soil year-round.
- pelagic zone - Main body of open water away from shore in a lake or the ocean.
- photic zone - Depth of water in a lake or the ocean to which sunlight can penetrate and photosynthesis can occur.
- plankton - Aquatic organisms that live in the water itself and cannot propel themselves through water.
- profundal zone - Deep water in a lake near the bottom where no sunlight penetrates.
- rain shadow - Land on the leeward side of a mountain range that receives very little precipitation.
- riparian zone - Interface between running freshwater and land.
- sublittoral zone - Part of the ocean floor that makes up the continental shelf.

- temperate deciduous forest - Temperate biome that receives moderate rainfall and consists mainly of deciduous trees such as maples.
- temperate grassland - Temperate biome that receives relatively low precipitation and consists mainly of grasses.
- temperate rainforest - Temperate biome that receives heavy rainfall and consists mainly of evergreen trees such as hemlocks.
- terrestrial biome - Biome on land.
- tree line - Edge of the zone at which trees are able to survive.
- tropical dry forest - Tropical biome that receives relatively low rainfall, has a dry season, and consists mainly of widely spaced, drought-adapted trees.
- tropical grassland - Tropical biome that receives relatively low rainfall, has a dry season, and consists mainly of grasses.
- tropical rainforest - Tropical biome that receives heavy rainfall and consists mainly of tall, broadleaf evergreen trees.
- tundra - Arctic biome where it is too cold for trees to grow.
- turnover - Process in which different layers of lake water intermix and bring nutrients from the bottom to the surface.
- upwelling - Process in which deep ocean water is forced to the surface by currents, bringing dissolved nutrients from the bottom to the surface.
- wetland - Area that is saturated or covered by water for at least one season of the year.

Chapter 8

Anthropocene

8.1 Introduction

Humans are having a massive affect in the world's ecosystems, extinction rates, and biome healt. Some call humans the new era in geological history of Earth.

Chapter Objectives

- Understand man's effect on Earths systems.
- Define and understand Anthropocene.
- Understand the term *shifting baselines*.

8.2 What is the Anthropocene?

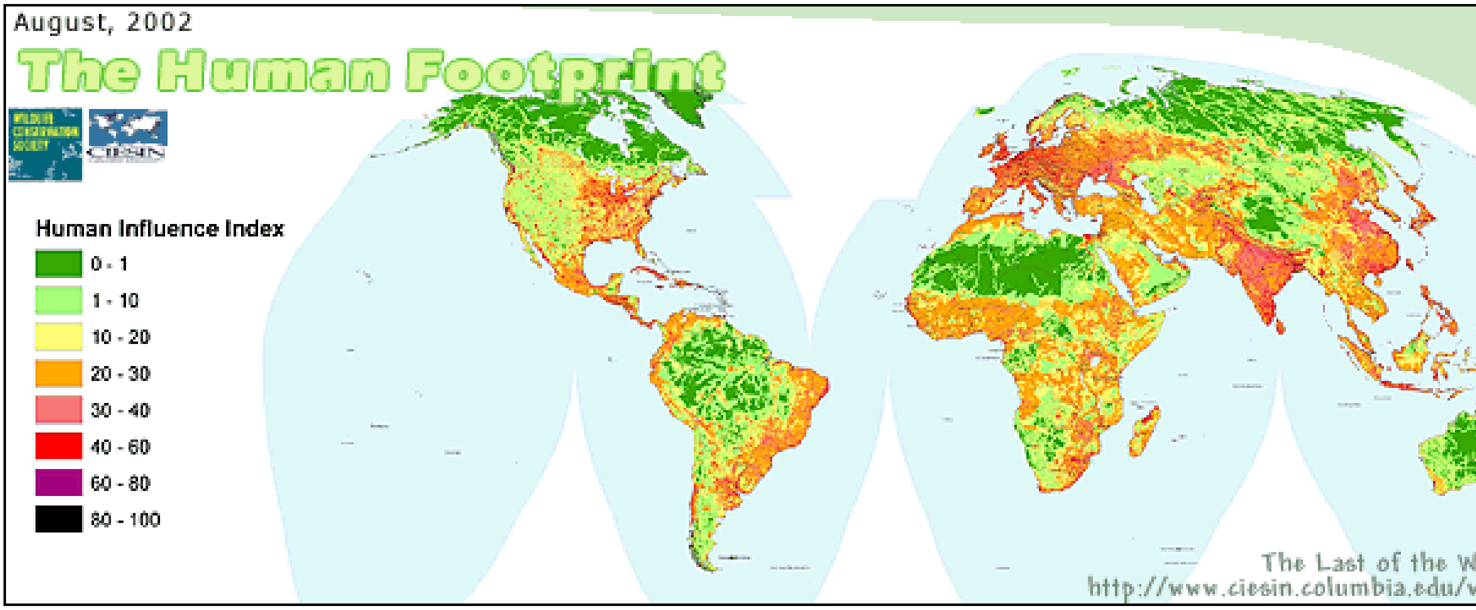
New geological ages are characterized by changes in global environmental conditions and large scale shifts in types of species. Recently Earth has entered into a new geological age: The Anthropocene, from anthropo = man and cene = new [geological age]. Humans are now changing the world on a global scale and ushering in the new era in geologic time.

> In a feat unprecedented for a single animal species, humanity's total energy use has now exceeded that of the entire ancient biosphere before oxygenic photosynthesis, reaching about a tenth of the energy processed by today's biosphere. From Lenton (2008).
>
> The biosphere itself, at all levels from genetic to the landscape, is increasingly a human product. (Allenby, 2000: 15).
>
> The interactions between environmental change and human societies have a long and complex history, spanning many millennia. They vary greatly through time and from place to place. Despite these space and time differences, in recent years a global perspective has begun to emerge that forms the framework for a growing body of research within the environmental sciences. Crucial to the emergence of the this perspective has been the dawning awareness of two fundamental aspects of the nature of the planet. The first is that the Earth itself is a single system, within which the biosphere is an active essential component. In terms of a sporting analogy, life is a player, not a spectator. Second, human activities are now so pervasive and profound in their consequences that they affect the Earth at a global scale in complex, interactive and accelerating ways; humans now have the capacity to alter the Earth System in ways that threaten the very processes and components, both biotic and abiotic, upon which humans depend. From International Geosphere Biosphere Program (2001), page 4.
>
> For all but the past 100–200 years of human history, humanity was clearly only a passenger on Spaceship Earth. But now, humankind has stepped out of its passenger seat and is wrestling the previous "pilots" for control of the ship. This seems a very dangerous course of action, as long as we don't know how the craft responds to perturbations, how the controls are wired, and what all the indicators signaling change are really trying to tell us. Andraea (2002) page 2.

Evidence of Human Change of the Planet

> Our analysis indicates that 83% of the earth's land surface is influenced directly by human beings, whether through human land uses, human access from roads, railways or major rivers, electrical infrastructure (indicated by lights detected at night), or direct occupancy by human beings at densities above 1 person per km^2. We refer to the human influence on the land's surface measure as the "Human Footprint." Last of the Wild Project, Center for International Earth Science Information Network (CIESIN), Earth Institute at Columbia University.

Table 8.1:



Human Influence on Earth. Click on image for a zoom. From Last of the Wild Project, Center for International Earth Science Information Network (CIESIN), Earth Institute at Columbia University.

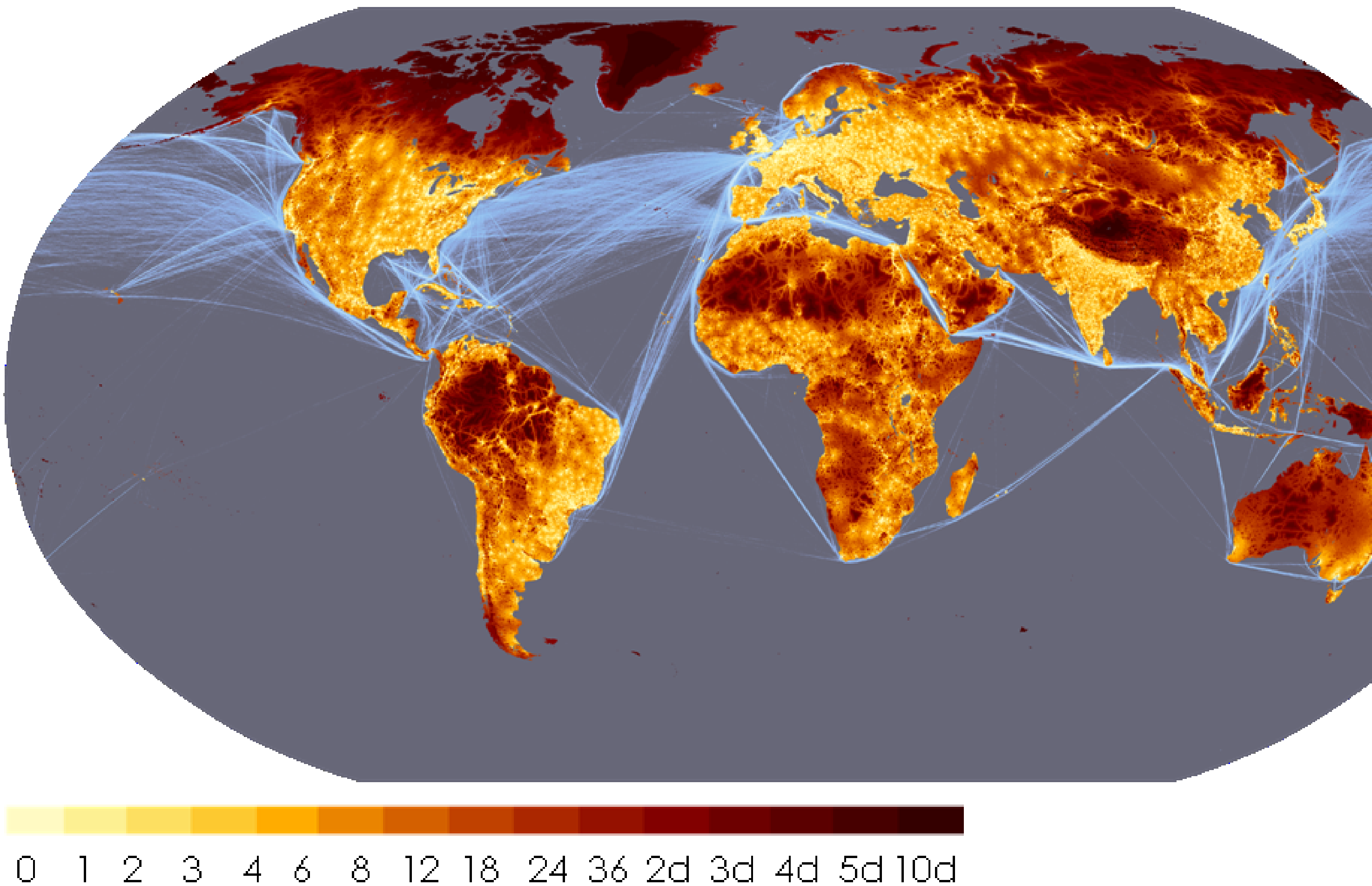
In the past hundred years, we have seen:

1. The complete conversion of 15% of all ice-free land surface to human use.
2. The partial conversion of 55% of all ice-free land surface to human use.
3. The fixation (conversion of atmospheric nitrogen into fertilizer) of 190 megatons of nitrogen per year (in 2005), compared with pre-agriculture terrestrial fixation of 150-190 megatons of nitrogen per year by natural processes (Smil, 2000: 248) In addition, burning of fossil fuels and industrial processes released 100 megatons of nitrogen oxides and ammonia into the atmosphere in 1995 (Galloway (2008).
4. The appropriation of 25% to 40% of total net primary productivity of the planet for human use.
5. Changes in the composition of the atmosphere.
6. The damming of most of the world's rivers. Humans have extensively altered river systems through impoundments and diversions to meet their water, energy, and transportation needs. Today, there are >45,000 dams above 15 m high, capable of holding back >6500 km^3 of water (1), or about 15% of the total annual river runoff globally. (Nillson et al, 2005).
7. The beginning of a massive extinction of life, about one species every 20 minutes (Wilson, 1992). One fifth of all species will be gone by 2030 if the present rate continues (Wilson, 2003: 102).
8. The total biomass of the world's population increased to roughly 40 megatons of carbon. To put this number into perspective, consider: The biomass of all life is roughly 500 Gigatons of carbon, the biomass of all wild vertebrates on land is roughly 5 megatons, and the biomass of all vertebrates in the ocean is about 50 megatons of carbon. We have eight time the mass of all wild land vertebrates, and about the same biomass as all the fish and whales in the ocean. Domesticated animals have a biomass of roughly 100 megatons of carbon. The biomass of our animals is about 20 times the mass of all wild vertebrates on land, and 50% larger than the mass of all vertebrates in the ocean. Smil (2002: 186, 283–284).
9. The mass of all motor vehicles is roughly 1,000 megatons. "Machines now need more carbon every year than humans do. The global food harvest now amounts to about 1.3 gigatons of carbon per

year, whereas almost 1 gigaton of fossil carbon is used annually to produce metals and plastic from which machines are assembled, and about 4 gigatons of carbon are used each year to power them." Smil (2002: 269).

10. The ability to reach almost any point on land within 48 hours. "Wilderness? Only 10% of the land area is remote – more than 48 hours from a large city." Travel time to major cities: A global map of Accessibility.

Table 8.2:



Time in days (d) to reach a place on land from a nearby major city. From Travel time to major cities: A global map of Accessibility.

When Did the Anthropocene Start?

The exact beginning of the anthropocene is still being debated, but Paul Crutzen and Eugene Stoermer have proposed that the anthropocene starts in the 18th century.

To assign a more specific date to the onset of the 'anthropocene" seems somewhat arbitrary, but we propose the latter part of the 18th century, although we are aware that alternative proposals can be made (some may even want to include the entire holocene). However, we choose this date because, during the past two centuries, the global effects of human activities have become clearly noticeable. This is the period when data retrieved from glacial ice cores show the beginning of a growth in the atmospheric concentrations of several 'greenhouse gases", in particular C02 and CH4. Such a starting date also coincides with James Watt's invention of the steam engine in 1784. About at that time, biotic assemblages in most lakes began to show large changes. From The Anthropocene by Paul Crutzen and Eugene F. Stoermer (2000).

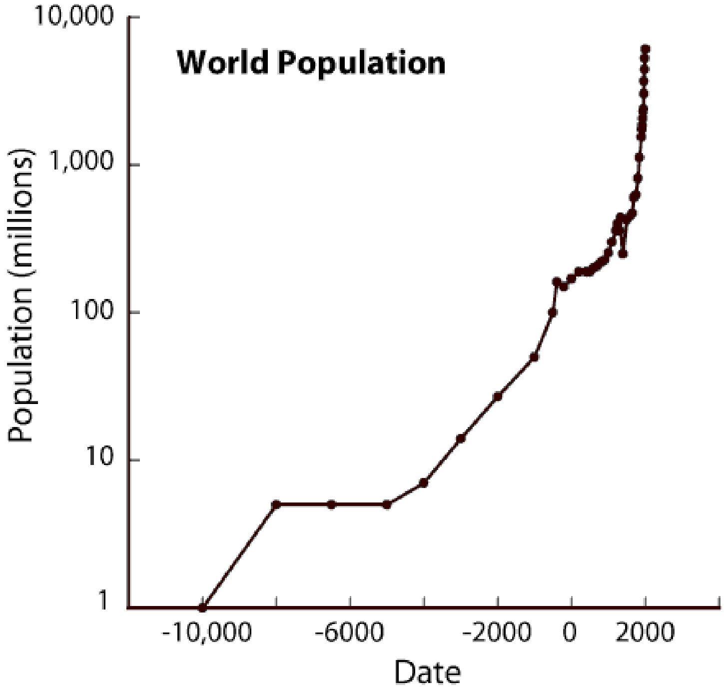
Cause

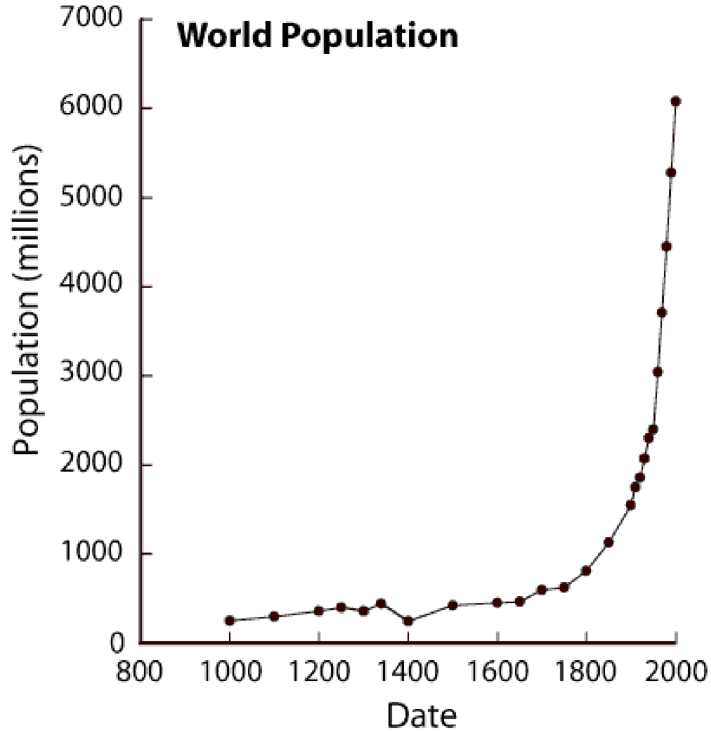
The anthropocene is the result of the vast expansion of human populations. If there were only a few million people on earth, we would not be changing the planet. But six and a half billion people are enough to produce important and noticeable changes.

Video of Population Growth View this video produced by the Population Connection, showing the growth of population on a map of the world, from 1 AD until the present. Each dot on the map represents 1,000,000 people. (This is a high-resolution video, click on the box in the lower right to view full screes). Growth is exponential, with most people being born in the last few decades.

The rate of population increase has been slowing. Still, we, as environmental geoscientists, must face the problem: What will happen to earth if the population continues to increase?

Table 8.3:





World Population: Left: Since prehistoric times (log scale).
Right: Since 800 AD (linear scale). Drawn using data from US Census Bureau, Historical Estimates of World Population, and World Population 1950-2050.
The recent, rapid increase of population led to the anthropocene. Note that the population is now increasing at the rate of one billion people every 13 years. This adds 1,000 dots every 10 years in the video.

Effects of the Anthropocene

There are three main effects on Earth by the Anthropocene:

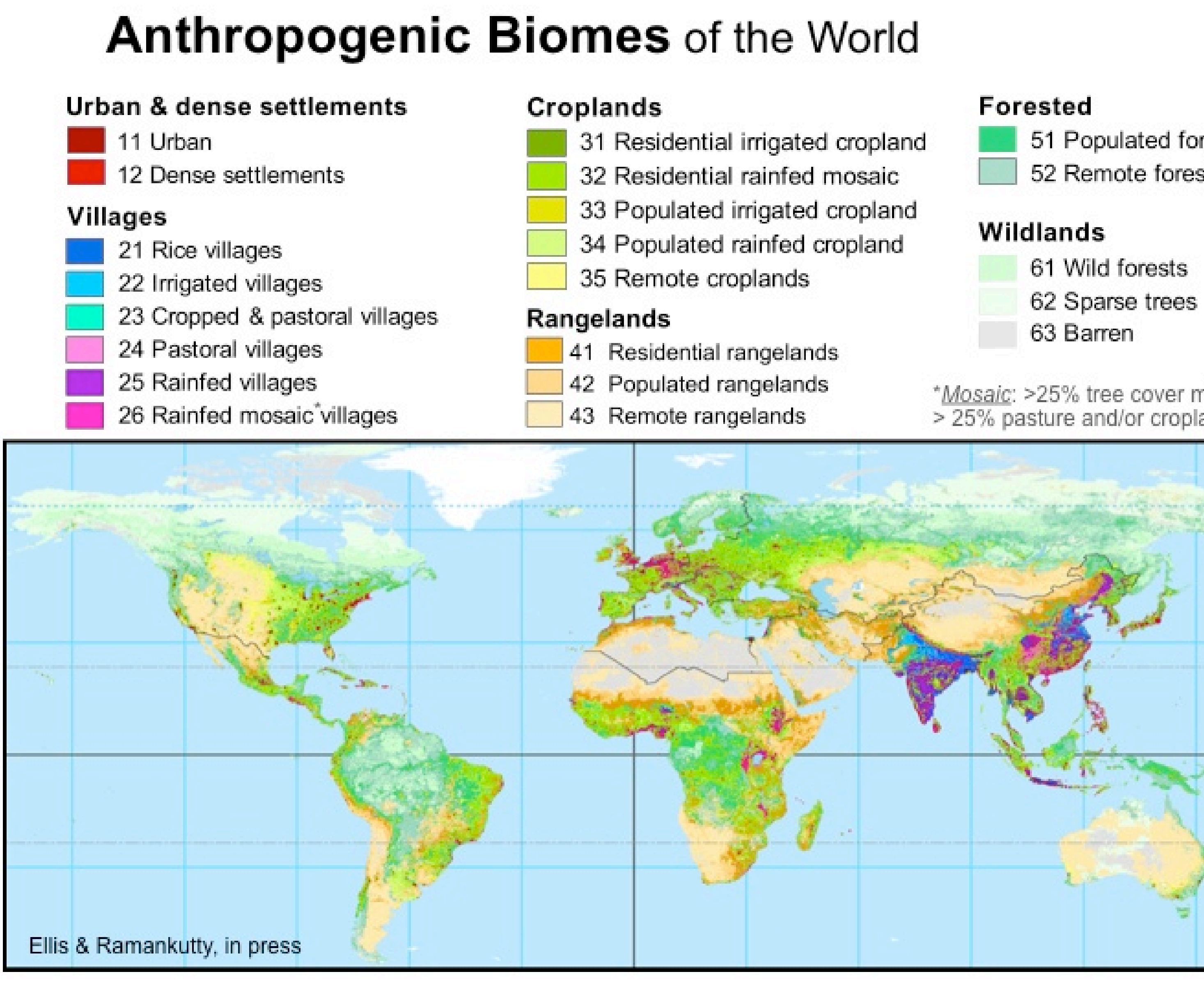
1. Biomes (ecosystems, extinction rates)
2. Ecosystem goods and services
3. Global climate change

Biome

Biomes organize the biological communities of the earth based on similarities in the dominant vegetation, climate, geographic location, and other characteristics (Biomes: Encyclopedia of Earth). In the past, they included deserts, tropical rain forests, tundra, freshwater streams and lakes, grasslands, estuaries, and open ocean. Now, all are influenced by people. Nature is imbedded within human systems according to Erle Ellis and Navin Ramankutty. They propose to replace the older biomes with new anthropogenic biomes based on the human influence on ecosystems.

Ecology needs to move beyond human footprints, impacts and domination. Ecosystem processes in anthropogenic biomes are primarily a function of human populations and their ecosystem interactions (land use). Forests, rangelands & croplands include people. Trees [are] mixed with croplands and housing. Anthropogenic landscapes are heterogeneous mixtures of different land use and land cover classes.

Table 8.4:



From Ellis and Ramankutty, Anthropogenic Biomes: A 21st century framework for ecology and the earth sciences. See: Anthropogenic Biomes article in Encyclopedia of Earth.

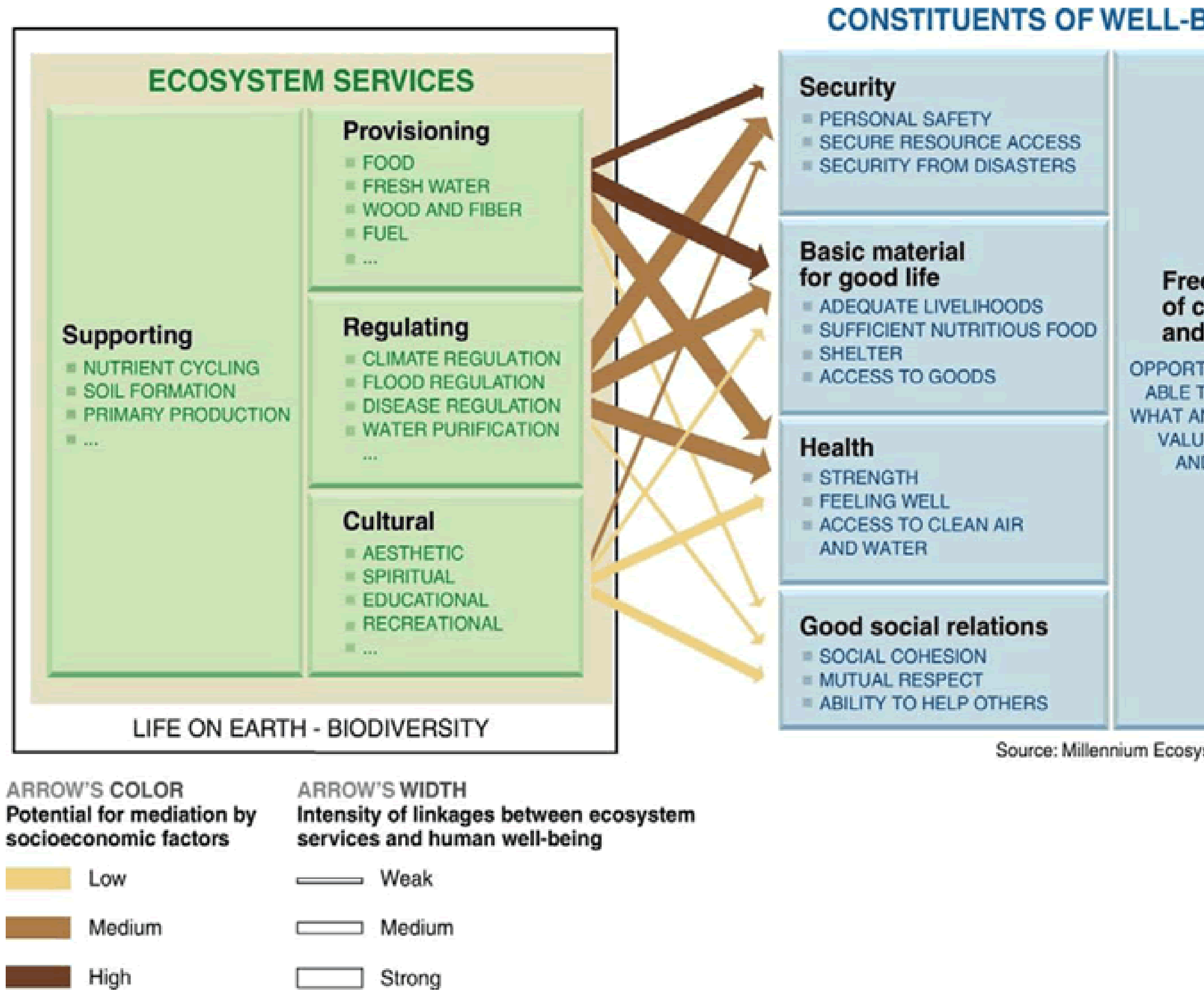
Ecosystem Goods and Services

Earth System processes provide environmental goods and services that sustain life and are essential for human well-being. These "ecosystem goods and services" include potable water, fertile soil, clean air and flood mitigation. Throughout history these have largely been taken for granted, because they were not significantly affected by human activities ... The magnitude of the human impacts on the environment – including direct effects of biogeochemical cycles, now threatens the quality and long-term delivery of ecosystem goods and services. From Global Land Project Transition Team (2005).

The water, food, fuel, fiber, oxygen, clean air, and places to live that we depend on are threatened.

Table 8.5: (continued)

Table 8.5:



As the world's population increases, we are reducing the ability of the systems to provide the services we need. Often, we are demanding more services than the ecosystems can provide. We may be reaching the point beyond which we cannot sustain our societies. Notice I wrote "may be." In 1798 Thomas Malthus published An Essay on the Principles of Population, then in 1968 Paul Erlich published his book The Population Bomb, and in 1972 the Club of Rome published the best selling environmental book in history, Limits to Growth. All sounded similar warnings. Then came the industrial revolution, the green revolution, increased food supplies, conservation of some resources, and the discovery of new resources. Today there are many more people enjoying life. Clearly, we are stressing the ability of earth to provide some services. But, we are not quite sure how close we are to the tipping point of an unsustainable future.

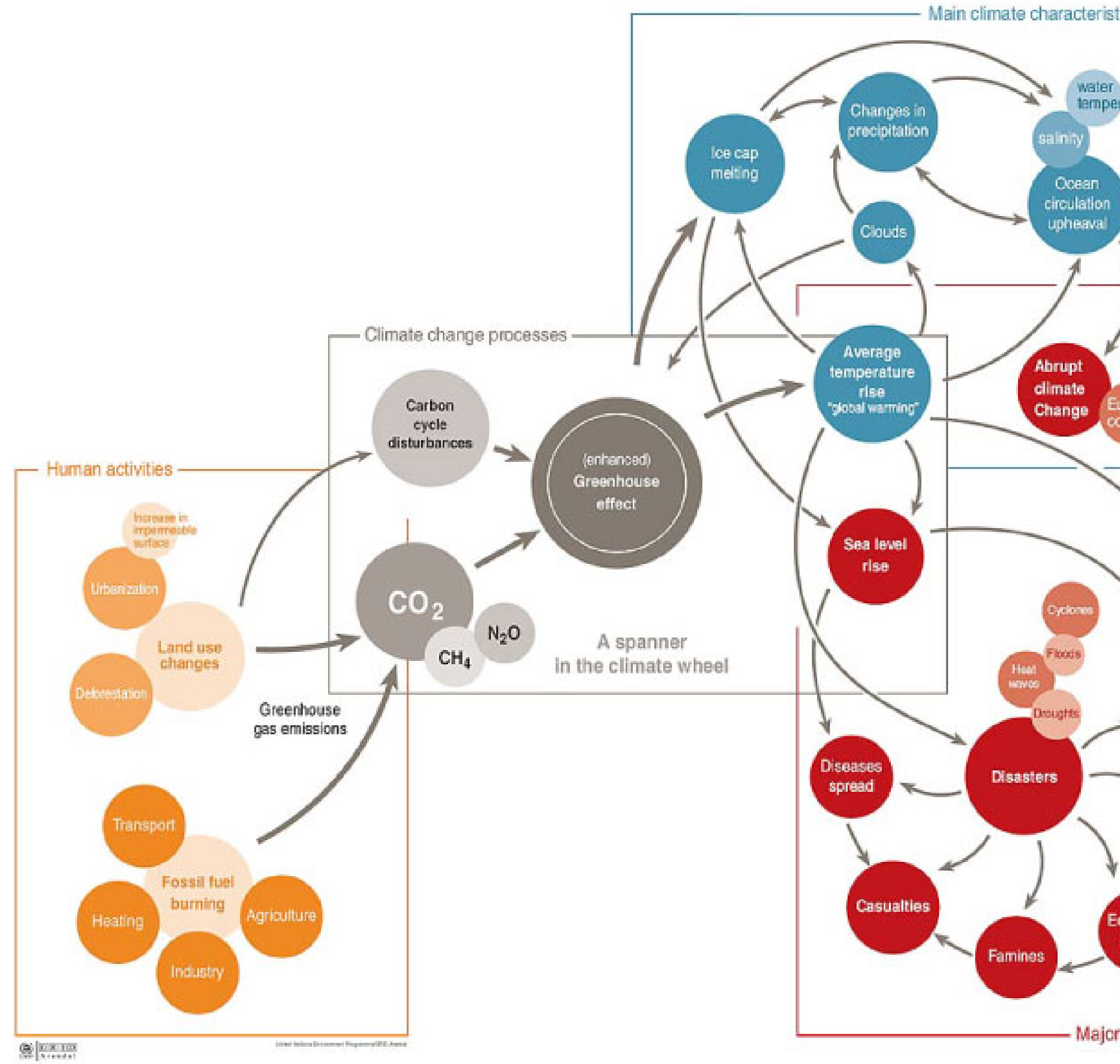
It's tough to make predictions, especially about the future.– Yogi Berra.

The Millennium Ecosystem Assessment Report of 2005 is the latest report to discuss the limits to growth. The report states we are using some resources faster than they can be replenished:

1. At least one quarter of important commercial fish stocks are over harvested.
2. From 5% to possibly 25% of global freshwater use exceeds long-term accessible supplies.
3. Some 15–35% of irrigation withdrawals exceed supply rates and are therefore unsustainable.
4. Reduction in stratospheric ozone is leading to increased UV radiation at earth's surface and to possibly more skin cancer.
5. Changes to ecosystems have contributed to a significant rise in the number of floods and major wildfires on all continents since the 1940s.
6. Actions to increase one ecosystem service often cause the degradation of other services.

Global Climate Change

Human activity has altered Earth's carbon and energy budget and other processes from the stratosphere, through the atmosphere to the land and down to the bottom of the sea. The figure shows the many ways we alter the nitrogen cycle, and some of the many feedback loops in the system.



The influence of human activity on the climate system. Click on image for a zoom. Image from UNESCO GRID-Arendal Vital Graphics-Climate Change.

8.3 Shifting Baselines

Did you ever meet a relative you had not seen in many years, and you noticed they had changed. Maybe they were slimmer. But people they saw often did not notice the change because it occurred slowly. Your baseline for comparison was several years old. The person's close friend's baseline was only a few days old.

Our ability to notice change is determined by our baseline.

 See the YouTube video Shifting Baselines in the Sound: http://www.youtube.com/watch?v=nkUEYbCSTnk (5:40)

If we have always lived in a city with smog or air pollution, we accept it as normal. We don't remember the days when the city had clear, clean, unpolluted air. Our baseline says the city is normal. A much older baseline says the city is polluted.

This is the phenomena of the shifting baseline. It colors our ability to notice environmental change because change is often slow, spanning generations. Sam Houston, visiting Texas today, would be shocked by the change. He would notice the buffalo and the wide-open spaces are gone, the night is not very dark, and the streams are muddy with few fish.

> You shoulda seen it when:

1. "You could see grass on the bottom in at least 10 to 12 feet of water."
2. "Oyster reefs were so abundant they were navigational hazards."
3. "Water flowed out of water wells at the land surface."
4. "The shad run was so strong it looked like you could walk across the river on their backs."
5. "You could paddle up any creek and fill the skiff with crab 'doublers'."
6. "Ducks and geese were there for the taking."
7. "Sturgeon roe was more abundant than Russian caviar."

> All these statements once applied to Chesapeake Bay and the Northern Neck. Today, it is hard to imagine what the Bay was like at the time Europeans arrived.
>
> Scientists refer to changes in perception (Old Timer's Syndrome) as "Shifting Baselines." From Northumberland Association for Progressive Stewardship.

Some examples:

1. People were once uncommon. It was possible to walk for days without meeting another person. Now, it is possible to walk for days without getting out of an urban area, say from Boston to Philadelphia.
2. Fish were once extremely plentiful. Many wrote that there were so many fish in the ocean it was almost possible to walk across a bay on the backs of the fish. Watch the YouTube video Emptied Oceans.
3. Streams and rivers were crystal clear. Beowulf could see clearly underwater in a river. The Rhine gold was visible on the bottom of the Rhine.
4. Once we stood in awe of the night sky with millions of stars spread across the black vastness of space. Our ancestors could clearly see stars and the milky way on moonless nights. Now most people can see only the brightest stars if they are lucky, or no stars if they are in a megapolis.

Table 8.7:

	Light pollution hides the beauty of the night sky.

5. The commonplace of the prehistoric landscape was very different from the modern landscape.

   Look at the changes in 152 years at Gowanus Bay in Brooklyn, New York. For more, read Civil society strategies on the Gowanus Canal by Lindsay Campbell. What would a resident from 1851 think of modern Brooklyn? What was your hometown like 100 years ago?

Table 8.8:

An 1851 oil painting by Australian artist Henry Gritten. The full title is ‘‘Sun Set at Gowanus Bay in the Bay New York” and the original hangs in the Allport Library and Museum of Fine Arts in Tasmania. The bay at that time was a ”Marshy inlet with game, fish, oysters; Gowanus oysters exported to Europe.” From Ephemeral New York.

Gowanus Bay in 2003. ”Ah, the Gowanus, that fetid Brooklyn canal synonymous with contamination and death. Sewage, industrial waste — perhaps even human remains — still molder at its murky bottom. On occasion, its famously noxious, sulfurous aroma wafts over its banks.” Click on the image for a zoom. From Wired New York Forum.

8.4 End of Chapter Review & Resources

Chapter Summary

Humans are having a profound effect on Earth's natural systems. The Anthropocene, from anthropo = man and cene = new [geological age]. Humans are now changing the world on a global scale and ushering in the new era in geologic time. As much as 83% of the earth's land surface is influenced directly by human beings. The Anthropocene probably started somewhere in the 18th century with the start of the industrial revolution, and is the result of the vast expansion of human populations. There are three main effects on Earth by the Anthropocene: 1) Biomes (ecosystems, extinction rates), 2) Ecosystem goods and services, 3) Global climate change. Shifting baselines means we have a hard time seeing the changes in the environment, as in cases where they are gradual over some years, the current state of the environment may seem normal and we no long really know what it ought to be like.

Review Questions

1. What is the Anthropocene?
2. What is a shifting baseline?
3. Give examples of how the Anthropocene has affected your local environment?
4. Give examples of how a shifting baseline might not allow you to notice all the changes to your environment? What do you elders say it used to be like?
5. What are three major effects of the Anthropocene on Earth's systems? Give some examples.

Further Reading / Supplemental Links

- The Economist: A Man-Made World: http://www.economist.com/node/18741749
- The National Geographic on the Anthropcene: http://ngm.nationalgeographic.com/2011/03/age-of-man/kolbert-text
- The BBC : Anthropocene - Have humans create a new geological age? http://www.bbc.co.uk/news/science-environment-13335683

Vocabulary to Know

- anthropocene
- shifting baselines
- extinction rates
- biome
- ecosystem services
- geological age

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Andraea, Meinrat O. 2002. Humanity: passenger or pilot on spaceship earth? Global Change Newsletter, December 2002, pages 2–7.

Crutzen, P. J. and E. F. Stoermer (2000). The Anthropocene. Global Change Newsletter (41): 17–18.

Galloway, J. N., A. R. Townsend, et al. (2008). Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. Science 320 (5878): 889-892. Humans continue to transform the global nitrogen cycle at a record pace, reflecting an increased combustion of fossil fuels, growing demand for nitrogen in agriculture and industry, and pervasive inefficiencies in its use. Much anthropogenic nitrogen is lost to air, water, and land to cause a cascade of environmental and human health problems. Simultaneously, food production in some parts of the world is nitrogen-deficient, highlighting inequities in the distribution of nitrogen-containing fertilizers. Optimizing the need for a key human resource while minimizing its negative consequences requires an integrated interdisciplinary approach and the development of strategies to decrease nitrogen-containing waste.

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Chapter 9

Populations & Urban Sprawl

Introduction

What exactly is the **population problem**? How can it be solved?

"***Solving the population problem is not going to solve the problems of racism... of sexism... of religious intolerance... of war... of gross economic inequality—But if you don't solve the population problem, you're not going to solve any of those problems. Whatever problem you're interested in, you're not going to solve it unless you also solve the population problem. Whatever your cause, it's a lost cause without population control.***" **–Paul Ehrlich, 1996** (From *Paul Ehrlich and the Population Bomb*, PBS video produced by Canadian biologist Dr. David Suzuki, April 26, 1996.)

Chapter Objectives

- Understand the history of views on population.
- Compare the importance of population size to that of population density.
- Explain how conservation biologists use Minimum Viable Population (MVP) and Population Viability Analysis (PVA).
- Explain how patchy habitats influence the distribution of individuals (animals) within a population.
- Define and explain population dispersion and pyramids.
- Interpret population pyramids to indicate populations' birth and death rates and life expectancy.
- Analyze the effect of age at maturity on population size.
- Understand survivorship and define population dynamics.
- Describe exponential (J-curve) growth and the logistic (S-curve) growth. Compare conditions.
- Clarify the relationship between population growth rate, birth rate, and death rate.
- Compare migration, immigration, nomadism, irruption, range expansion, and colonization in terms of their effects on population density.
- Give examples of population growth patterns in nature.
- Describe , and explain the conditions under which it occurs.
- Analyze the concept of carrying capacity in terms of population growth and resource availability.
- Compare and contrast density-dependent and density-independent limiting factors.
- Relate predator-prey cycles to density-dependent population control.
- Compare and contrast the adaptations and environmental characteristic of r-selected species to those of K-selected species.

- Contrast the Neo-Malthusian or ''limits to growth'' and cornucopian or ''technological fix'' views of human population growth.
- Describe the four stages of human population growth as outlined by the demographic transition model.
- Using age-sex structures, contrast population growth in developed countries to growth in undeveloped countries.
- Explain the concept of replacement fertility rate.
- Discuss the implications of Stage 5 population dynamics.
- Know and understand predictions for future worldwide human population growth.
- Explore the concept of sustainability as a goal for economic, social, and environmental decision-making.
- Explain the tool of ecological footprint analysis as a means of evaluating the sustainability of lifestyles for individuals, countries and the world.
- Calculate your ecological footprint and compare it to averages for your country and the world.
- Recognize our human potential to make decisions which could direct future population growth.
- Explore some options for social, political and cultural change, and environmental conservation which could help to balance population dynamics and resource utilization.

9.1 Characteristics of Populations

Humans have shown concern for **overpopulation** since the Ancient Greeks built outposts for their expanding citizenship and delayed age of marriage for men to 30. In 1798, Thomas Malthus predicted that the human population would outgrow its food supply by the middle of the 19th century. That time arrived without a Malthusian crisis, but Charles Darwin nevertheless embraced Malthus' ideas and made them the foundation of his own theory of evolution by natural selection. In a 1968 essay, *The Tragedy of the Commons*, Garrett Hardin exhorted humans to "relinquish their freedom to breed," arguing in the journal, *Science*, that "the population problem has no technical solution," but "requires a fundamental extension in morality." In 1979, the government of China instituted a "birth planning" policy, charging fines or "economic compensation fees" for families with more than one child. Others have opposing views, however. Julian Simon, professor of Business Administration and Senior Fellow at the Cato Institute, argued that *The Ultimate Resource* is population, because people and markets find solutions to any problems presented by overpopulation. A group known as **cornucopians** continues to promote the view that more is better.

Figure 9.1: The Chinese government mandates population control by charging

Would you support a law forbidding you to marry until a certain age? Do you know how such a law would affect population growth? Would you limit the size of all families to one child (**Figure** 9.1)? Do you believe families should welcome as many children as possible? Should these decisions be regulated by law, or by individual choice? Clearly, the ‘‘population problem” reaches beyond biology to economics, law, morality, and religion. Although the latter subjects are beyond the scope of this text, the study of population biology can shed some light on human population issues. Let’s look at what biologists have learned about natural populations. Later, we will look more closely at human populations, and compare them to populations in nature.

Measuring Populations

In biology, a **population** is a group of organisms of a single species living within a certain area. Ecologists study populations because they directly share a common gene pool. Unlike the species as a whole, members of a population form an interbreeding unit. Natural selection acts on individuals within populations, so the gene pool reflects the interaction between a population and its environment.

Biologists study populations to determine their health or stability, asking questions such as:

- Is a certain population of endangered grizzly bears growing, stable, or declining?
- Is an introduced species such as the zebra mussel or purple loosestrife growing in numbers?
- Are native populations declining because of an introduced species?
- What factors affect the growth, stability, or decline of a threatened population?

The first step in characterizing the health of a population is measuring its size. If you are studying the population of purple loosestrife plants on your block , you can probably count each individual to obtain an accurate measure of the population’s size. However, measuring the population of loosestrife plants in your county would require sampling techniques, such as counting the plants in several randomly chosen small plots and then multiplying the average by the total area of your county. For secretive, highly mobile, or rare species, traps, motion-detecting cameras, or signs such as nests, burrows, tracks, or droppings allow estimates of population size.

Figure 9.2: Purple loosestrife plant populations show patchiness due to uneven distribution of their wetland habitats, and clumped dispersion, due to local variation in soils.

Two problems with absolute size lead ecologists to describe populations in other terms. First, because your county may not be the same size as others, the total number of individuals is less meaningful than the **population density** of individuals – the number of individuals per unit area or volume. Ecologists use population densities more often for comparisons over space or time, although total number is still important for threatened or endangered species.

Concern about threatened and endangered species has led conservationists to attempt to define **minimal viable population** size for some species. A species’ **MVP** is the smallest number of individuals which can exist without extinction due to random catastrophic variations in environmental (temperature, rainfall), reproduction (birth rates or age-sex structure), or genetic diversity. In 1978, Mark Shaffer incorporated an estimate for grizzly bear MPV into the first **Population Viability Analysis (PVA)**, a model of interaction between a species and the resources on which it depends. PVAs are species-specific, and require a great deal of field data for accurate computer modeling of population dynamics. PVAs can predict the probability of extinction, focus conservation efforts, and guide plans for sustainable management.

Patterns in Populations I: in Space (or Patterns in Space)

A second problem in measuring population size relates to the distribution of individuals within the population's boundaries. If your county has extensive wetlands in the southern half, but very few in the north, a countywide population density estimate of purple loosestrife, which grows primarily in shallow freshwater pond edges, marshes, and fens, would be misleading (**Figure** 9.2). **Patchy** habitat – scattered suitable areas within population boundaries – inevitably leads to a patchy distribution of individuals within a population. On a smaller scale, plants within even a single wetland area may be **clumped or clustered** (grouped), due to soil conditions or gathering for reproduction. The characteristic pattern of spacing of individuals within a population is **dispersion** (**Figure** 9.3). Clumped dispersion is most common, but species that compete intensely, such as cactus for water in a desert, show **uniform**, or evenly spaced, dispersion.

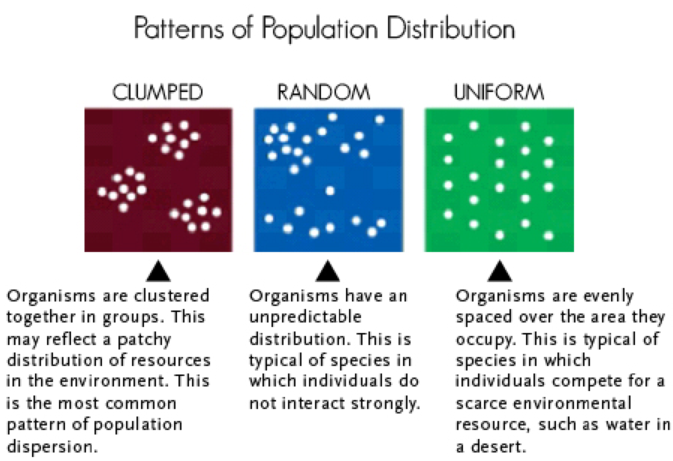

Figure 9.3: Populations of cacti in the desert, such as this group of cholla, show uniform, or even, dispersion due to fierce competition for water. The diagrams to the right show nearly uniform (top), random (middle), and clumped (bottom) dispersion patterns.

Other species, whose individuals do not interact strongly, show a **random**, or unpredictable, distribution. Useful measures of population density must take into account both patchiness of habitat and dispersion of individual organisms within the population's boundaries.

Age-Sex Structure of a Population

Density and dispersion describe a population's size, but size is not everything. Consider three populations of endangered grizzly bears, each containing one individual per 20 km^2, and a total of 100 individuals in 2,000 km^2. These populations are "equal" with respect to size. One population, however, has 50 immature

Figure 9.4: Grizzly bear populations include adults up to 25 or 30 years old, capable of reproducing, and young immature bears under 6 years old. Healthy populations include roughly equal proportions of each age group.

(non-reproducing young) bears and 50 adult bears able to reproduce. A second population has the same number of immature and adult bears, but of the 50 adults, 45 are male. The third population has 30 immature bears and 70 bears of reproductive age. Which population is healthiest (**Figure** 9.4)?

The answer is not simple, but age and sex differences between populations are significant indicators of health. Biologists concerned about a population's future study age and sex within the population and then graph the results to show the **age-sex structure** as a **population pyramid,** although the result does not always resemble a pyramid. The X-axis in this double bar graph indicates percentage of the population, with males to the left and females to the right. The Y-axis indicates age groups from birth to old age.

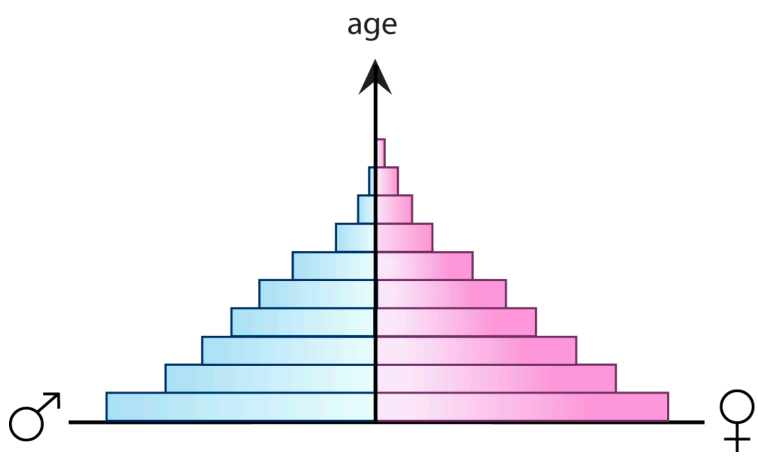

Figure 9.5: A generalized age-sex structure or population pyramid shows the proportion of males and females (X-axis) at each age level (Y-axis). This example shows a slightly higher proportion of females compared to males, and a much higher proportion of young individuals compared to old.

The population in the generalized example (**Figure** 9.5) contains a large proportion of young individuals, suggesting a relatively high **birth rate** (number of births per individual within the population per unit time). The bars narrow at each age interval, showing that a significant number of individuals die at every age. This relatively high **death rate** (number of deaths per individual within the population per unit time) indicates a short **life expectancy**, or average survival time for an individual. Note the slightly greater proportion of females compared to males at each age level. Careful study could determine whether the cause for this imbalance is the ratio of female to male births, or higher death rates for males throughout a shorter lifespan. You will learn in a later lesson that this pattern is characteristic of human populations in less developed countries.

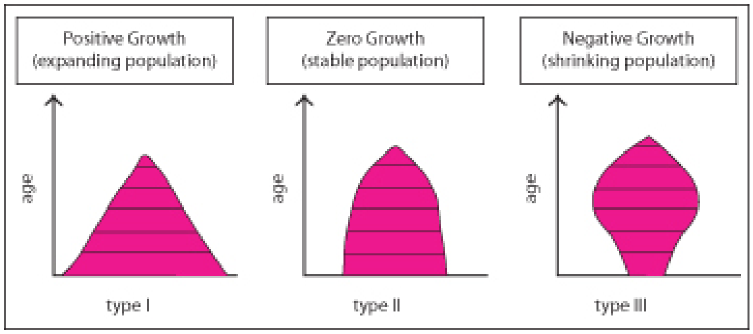

Figure 9.6: Age structures can reveal a population

A population's age structure may reveal its health (**Figure** 9.6). A growing population (Type I) usually has more young individuals than adults at beyond reproductive age. A stable population (Type II) often has roughly equal numbers of young members and adults. A declining population shows more adults and fewer young (Type III). Sex structure may also affect the health of a population. Sex determination in sea turtles, for example, is temperature-dependent; lower egg incubation temperatures produce males, while temperatures as little as 1-2°C higher produce females (**Figure** 9.7). Some biologists predict that climate change may result in sea turtle sex structure shifts toward females, which could further endanger already threatened species. Continued monitoring of age-sex structures among sea turtles might be able to detect such changes before they become irreversible.

Figure 9.7: The sex of a sea turtle is determined by the temperature at which it develops

Although it is not shown in population pyramids, an important factor affecting population size is the age at which individuals become able to reproduce (**Table** 9.1). Recall that **age at maturity** (when reproduction becomes possible) was the factor that even ancient Greeks recognized could affect population growth, when they prohibited marriage for males under the age of 30. We will return to this relationship in a later lesson, but for now, try to grasp it intuitively: if a person delays reproduction until age 30 and then has one child each year for two years, his or her **fertility** is 2. A person who has two children, one each year, beginning at age 20 also has a fertility of 2. Assume that these four children are born in the same two-year period, and that each offspring reproduces two children at the same age as his/her parent did. Sixty years after the initial four childbirths, the "delayed reproduction" individual will have 2 X 2 X 2 = 8 descendants. However, the early reproducing family will have 2 X 2 X 2 X 2 = 16 offspring –

double the population increase of the first family. Do you think this could this be one way to slow human population growth?

Table 9.1: **Number of Offspring Produced Over Time**

Age at First Reproduction	Initial Reproduction	20 years later	30 years later	40 years later	60 years later
20 years	Generation 1: 2 offspring	Generation 2: 4 offspring		Generation 3: 8 offspring	Generation 4: **16**
30 years	Generation 1: 2 offspring		Generation 2: 4 offspring		Generation 3: **8**

Patterns in Populations Through Time

The characteristics of populations introduced above – birth rate, death rate, and life expectancy – interact to form several basic strategies for survival. Insurance companies began investigations into life expectancies for various groups of people – males vs. females, for example – and compiled the data in *life tables.* Biologists plot these patterns through time in **survivorship curves**, which graph the number of all individuals still living (in powers of ten, on the Y-axis) for each age (on the X-axis). The three basic types of survivorship curves are illustrated in **Figure** 9.8.

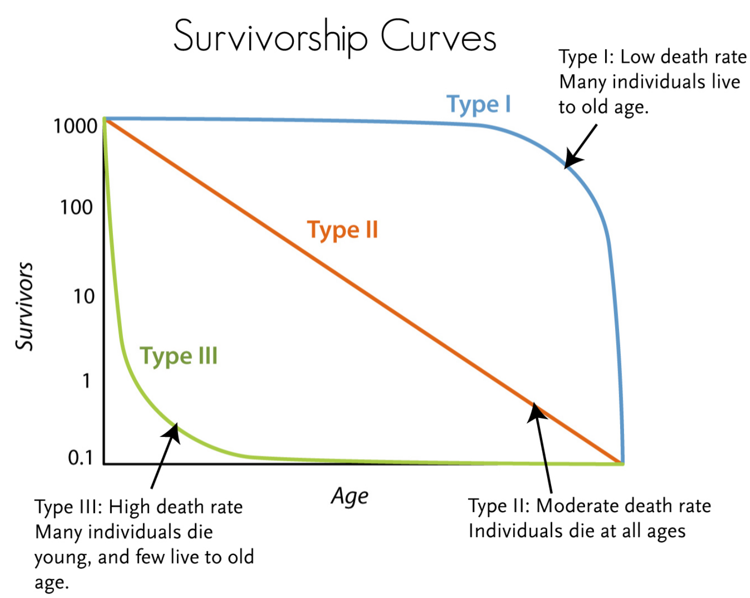

Figure 9.8: Survivorship curves correlate with strategies species use to adapt to various environments. Large organisms in relatively stable environments have few offspring but high levels of parental care; most individuals survive to old age (Type I). Smaller organisms in less stable environments produce many offspring but provide little parental care, and few survive to old age (Type III). Type II species show intermediate characteristics in response to a death rate which remains constant throughout life.

Species showing a Type I pattern have the highest survival rates, with most individuals living to old age. Many large animals, including humans, show this ‘‘late loss” pattern of survivorship; few offspring, high levels of parental care, and low ‘‘infant” death rates characterize Type I species. As we will see in a later lesson, human populations in rich countries fit this pattern more closely than do those in undeveloped countries.

Species with Type III survivorship patterns experience high death rates among offspring; relatively few survive to old age. Most plants and invertebrates and many fish show this "early loss" pattern. Parents invest most of the reproductive energy in high numbers of offspring to offset the high death rates, and little or no energy remains for parental care.

Species showing intermediate, Type II survivorship curves experience uniform death rates throughout their lives. Some birds and many asexual species show this "constant loss" pattern.

We'll look at these strategies more closely in the next lesson as we study how populations grow and change: population dynamics.

9.2 Population Dynamics

Imagine a huge bowl of your favorite potato salad, ready for a picnic on a beautiful, hot, midsummer day. The cook was careful to prepare it under strictly sanitary conditions, using fresh eggs, clean organic vegetables, and new jars of mayonnaise and mustard. Familiar with food poisoning warnings, s/he was so thorough that only a single bacterium made it into that vast amount of food. While such a scenario is highly unrealistic without authentic canning, it will serve as an example as we begin our investigation of how populations change, or **population dynamics**. Because potato salad provides an ideal environment for bacterial growth, just as your mother may have warned, we can use this single bacterial cell in the potato salad to ask:

How Do Populations Grow Under Ideal Conditions?

Given food, warm temperatures, moisture, and oxygen, a single aerobic bacterial cell can grow and divide by binary fission to become two cells in about 20 minutes. The two new cells, still under those ideal conditions, can each repeat this performance, so that after 20 more minutes, four cells constitute the population. Given this modest doubling, how many bacteria do you predict will be happily feeding on potato salad after five hours at the picnic? After you've thought about this, compare your prediction with the "data" in **Table ??**.

Table 9.2: Like many populations under ideal conditions, bacteria show exponential or geometric growth. Each bacterium can undergo binary fission every 20 minutes. After 5 hours, a single bacterium can produce a population of 32,768 descendants.

Table 9.2:

Time (Hours and Minutes)	**Population Size** (Number of Bacteria)
0	1
20 minutes	2
40 minutes	4
1 hour	8
1 hour 20 minutes	16
1 hour 40 minutes	32
2 hours	64
2 hours 20 minutes	128
2 hours 40 minutes	256
3 hours	512
3 hours 20 minutes	1024
3 hours 40 minutes	2048
4 hours	4096
4 hours 20 minutes	8192
4 hours 40 minutes	16,384
5 hours	**32,768**

(*Source:* CK-12 Foundation, *License:* CC-BY-SA)

Are you surprised? This phenomenal capacity for growth of living populations was first described by Thomas Robert Malthus in his 1798 *Essay on the Principle of Population.* Although Malthus focused on human populations, biologists have found that many populations are capable of this explosive reproduction, if provided with ideal conditions. This pattern of growth is **exponential**, or **geometric growth**: as the population grows larger, the rate of growth increases. If you have worked compound interest problems in math or played with numbers for estimating the interest in your savings account, you can compare the growth of a population under ideal conditions to the growth of a savings account under a constant rate of compound interest. The graph in **Figure** 9.9, using potato salad bacterial "data," shows the pattern of exponential growth: the population grows very slowly at first, but more and more rapidly as time passes.

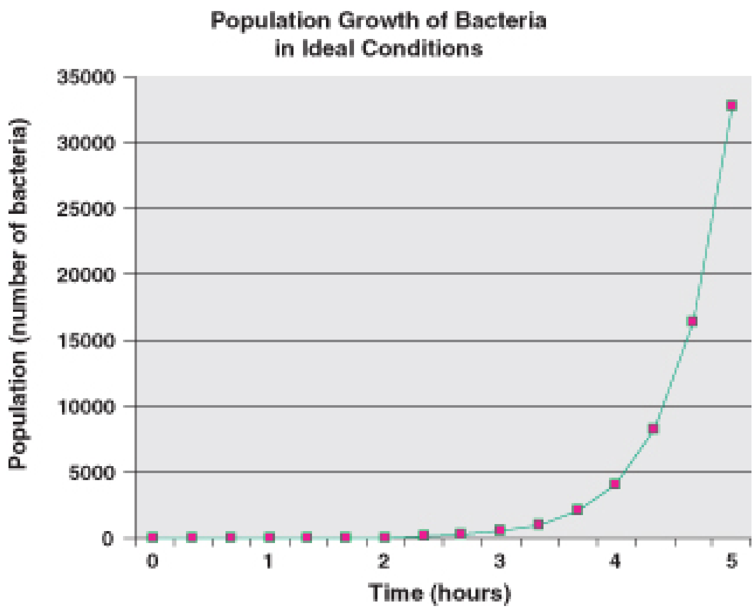

Figure 9.9: Exponential or geometric growth is very slow at first, but accelerates as the population grows. Because rate of growth depends on population size, growth rate increases as population increases. Most populations have the ability to grow exponentially, but such growth usually occurs only under ideal conditions that are not found in nature. Note the

Of course, if bacterial populations always grew exponentially, they would long ago have covered the Earth many times over. While Thomas Malthus emphasized the importance of exponential growth on population, he also stated that ideal conditions do not often exist in nature. A basic limit for all life is energy. Growth, survival, and reproduction require energy. Because energy supplies are limited, organisms must "spend" them wisely. We will end this lesson with a much more realistic model of population growth and the implications of its limits, but first, let's look more carefully at the characteristics of populations which allow them to grow.

For a discussion of exponential growth, see (**I&E 1e**): http://www.youtube.com/watch?v=-3MI0ZX5WRc (10:43).

Births and Deaths: Balancing Costs of Reproduction and Survival

The **growth rate of a population** is the change in population size per member of the population per unit of time. The symbol r denotes growth rate. Growth rate clearly depends on **birth rate** b, the number of births per individual within the population per unit of time, as well a **death rate** d, the number of deaths per individual per unit of time. The following equation calculates growth rate, according to our

Figure 9.10: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/176

preliminary understanding:

$\boldsymbol{r = b - d}$

growth rate = birth rate – death rate

If birth rate exceeds death rate, r is positive and the population grows. If death rate exceeds birth rate, r is negative and the population declines. And if birth rate and death rate are in equilibrium, growth rate is zero, and the population remains stable. In a stable population, each individual, on the average, produces one offspring which survives long enough to reproduce itself. Mere survival is not success in the game of life; natural selection requires that survivors reproduce. As Malthus realized, nearly all species have the *potential* to grow – to reproduce many more than just a single replacement offspring. However, species vary in the strategies they use to achieve reproductive success, making trade-offs between the energy and time ‘‘costs” of survival and those of reproduction. Age at first reproduction, frequency of reproduction, number of offspring, parental care, reproductive lifespan, and offspring death rate are some of the traits which build strategies for successful reproduction.

Analyzing extreme examples can help you understand the trade-offs species must make between survival and reproductive success. Let’s compare two groups of birds. Somewhat like precocious children who mature early, *precocial* birds run around to find their own food soon after hatching. Geese, ducks, and chickens use this strategy for raising their young (**Figure** 9.11). Often living and nesting on the ground, precocial species are subject to high predation rates, so few survive long enough to reproduce. Therefore, those who do reproduce lay many eggs at once, and these eggs are large. The young emerge well-developed, ready to feed and escape predators soon after hatching. Precocial species invest a great deal of energy in a large number of offspring but do not spend much energy on parental care, because even though some offspring are likely to die, others will survive long enough to reproduce.

Figure 9.11: Geese and ducks use a

Contrast this precocial strategy with the opposite, *altricial* strategy used by robins and hummingbirds

(**Figure** 9.12). These birds hatch helpless and naked, completely unprepared for independent life. Parents invest little energy in just a few, small eggs; hummingbirds' eggs are the smallest in the bird world, and average two per nest. However, survival of these offspring matters a great deal, because there are so few. So, parents build elaborate nests safely hidden in trees and invest a great deal of energy hunting for food around-the-clock until the young have developed enough to fledge and find food on their own.

Figure 9.12: Hummingbirds illustrate an

Precocial and altricial birds play by the rules of costs and benefits, each group using a different strategy. Cowbirds, however, make up their own rules, earning them the title of ''parasites'' in the bird world. How can a bird be a parasite? Cowbirds are altricial, but they parasitize by laying their eggs in other birds' nests, thereby escaping the high costs of parental care (**Figure** 9.13). Cowbird eggs are usually slightly larger and hatch a little sooner than the host eggs affording cowbird parents a bit of extra energy. ''Early bird'' hatchlings do indeed ''get the worm,'' easily out-competing their smaller host siblings for parental food deliveries. Sometimes, they are strong enough to ungratefully oust their ''sibs'' from the nest. On the other hand, host parents occasionally recognize and eject the foreign egg before it hatches. Yellow warblers simply block off the offending egg (along with their own eggs) by building a new nest bottom. They then lay a new clutch of their own eggs (The eggs are not their primary energy investment). A five-''story'' nest holds the record for yellow warbler (and cowbird?) determination!

Figure 9.13: A brown-headed cowbird egg in a phoebe

Many species fall in between the extremes of precocial and altricial strategies, but all must make trade-offs between the costs of reproduction and those of surviving predation, competition, and disease, in order to ensure that at least one offspring per adult survives long enough to reproduce. It's worth reprising the survivorship curves introduced in the previous lesson to illustrate these trade-offs (**Figure** 9.14). Which curve illustrates the precocial strategy used by ducks, chickens, and grouse? Which curve demonstrates the altricial strategy of robins and hummingbirds? What shape do you think a cowbird's survivorship curve might take?

One more strategy, introduced in the last lesson, involves variation of age at maturity. All other factors being equal (number and size of offspring, survival rates, and more), delayed reproduction lowers population growth rate. Bald eagles require five years of growth before they are able to reproduce. If they were to lay the same number of eggs during their first year, those first-year offspring and several generations of *their* offspring, as well as the parents, would be able to reproduce during that time, tremendously increasing

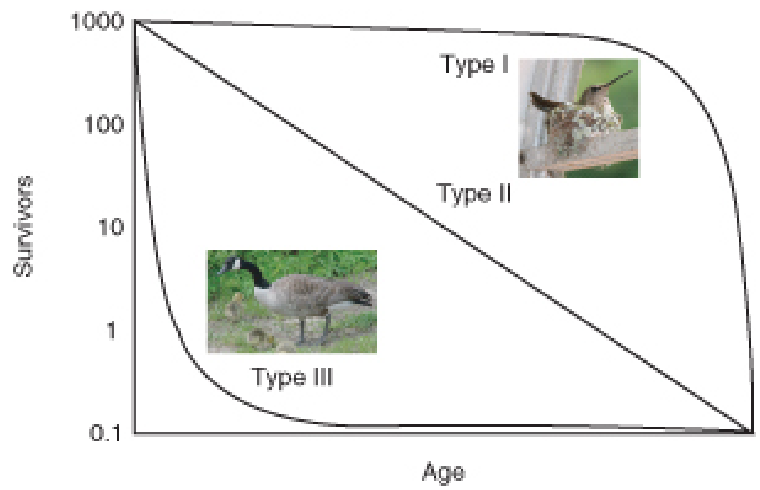

Figure 9.14: Survivorship curves show the various strategies for achieving population growth by adjustments in birth rate and death rate. Recall that

the overall population. By delaying reproduction, bald eagles not only ensure good energy supplies for reproduction at maturity, but also limit population density to suit their large bodied, long-lived life history.

Migration and Other Movements Affect Population Densities

Populations change not only through births and deaths, but also via **immigration**, movement of individuals into a population from other areas, and **emigration**, movement of individuals out of a population. If we add per capita rates of immigration and emigration into our equation for population growth rate, it becomes:

$r = (b + i) - (d + e)$

growth rate = (birth rate + immigration rate) – (death rate + emigration rate)

Many kinds of movement adaptations regularly add to or subtract from population density.

- Most species have some means of **dispersal** – movement of offspring away from the parents. This ‘‘behavior” reduces competition within the population, promotes colonization of suitable habitat, and improves reproductive success. Some dispersal mechanisms take advantage of natural energy in the environment. For example, dandelion seeds grow ‘‘parachutes” which allow wind to carry them far from their parents – and sometimes entirely out of a population (**Figure** 9.15). For the same reason, immobile animals such as corals often produce motile larva. Mobile animals often evolve behaviors which ensure dispersal. A lone gray wolf which leaves its birth pack must find a mate and an unoccupied territory in order to reproduce; within the pack, usually only the alpha male and female have offspring. Dispersal behaviors are common in the living world; have you - as a teenage high school student, begun to feel stirrings of the wish to leave home?

- **Migration**, the direct, often seasonal movement of a species, is a predictable change for some animal populations. Many northern hemisphere birds, such as Swainson's Hawks (**Figure** 9.16), migrate thousands of miles southward in the fall and return north to nest in the spring in order to follow summer's long days which provide extra hunting time and a greater abundance of food.

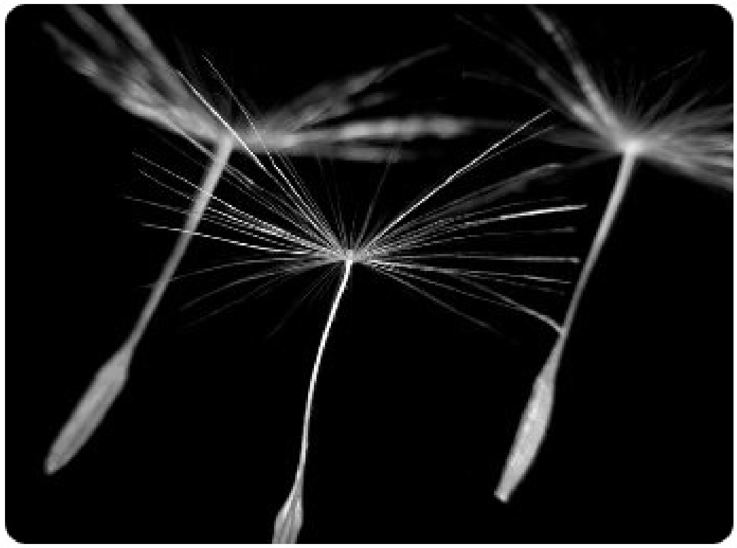

Figure 9.15: Wind carries dandelion seeds away from their parent plants. The parachute adaptation allows for dispersal, reducing competition within the population and promoting colonization of suitable habitat.

Apparently, energy benefits outweigh costs for this annual long-distance commute. Elk migrate vertically – up the mountains in spring as snow recedes and down the mountains in fall as winter advances. Monarch butterflies migrate in "shifts"; somewhat like a relay team, successive generations divide the task of moving from Mexican wintering grounds to northern summer habitats. Such migrations do not add to or subtract from populations as much as they move entire populations from one set of boundaries and environmental conditions to another. Some species, such as Peregrine Falcons, have both migratory and non-migratory forms, so their populations may grow or decline with migration. Gray Whales migrate 12,500 miles from Alaska to Mexico for calving, but at least one population limits its northward journey to the Oregon coast (**Figure** 9.17). Seasonal densities of migratory species vary considerably, but resources and environmental benefits vary as well. Migration can affect all four factors of the growth rate equation.

Other types of movement are less predictable, but still may affect population growth.

- **Nomadism**, regular, wide-ranging wandering behavior, allows some species to compensate for fluctuating food sources. Normally arctic species, Snowy Owls occasionally venture as far south as Texas, southern Russia, and northern China (**Figure** 9.18). Bohemian waxwings are notoriously nomadic, feeding on highly variable berry supplies.

- **Irruptions** or **invasions** are irregular movements, often caused by food source failures. Owls such as Great Grays and Boreals occasionally invade northern US states from their Canadian homes when rodent populations decline. Some may remain to nest following such an irruption.
- **Range expansion** involves the gradual extension of a population beyond its original boundaries. Recent examples in the US include Cardinals, now common in northern areas where they were originally absent. The Swainson's Thrush follows an indirect and unnecessarily long migration path - retracing, scientists believe, a range expansion from 10,000 years ago. **Intentional introductions** of non-native species such as the House Sparrow and **reintroductions** of extirpated species such as Peregrine Falcons throughout the Eastern US are human-initiated colonizations, which are often followed by range expansions.
- Closely related to range expansion is **colonization**, but the latter often involves newly created, or at least newly found, habitats. Illustrating both range expansion and colonization, the small red-eyed

Figure 9.16: Entire populations of Swainson

Figure 9.17: Gray Whales migrate up to 12,500 miles

Figure 9.18: Normally arctic species, Snowy Owls occasionally wander as far south as Texas, southern Russia, and northern China. This nomadic behavior allows them to feed on prey which have unpredictable fluctuations in population density.

dragonfly spread throughout Europe in the late 20th century and colonized Britain in 1999 (**Figure** 9.19).

Figure 9.19: Small red-eyed dragonflies expanded their range throughout northwest Europe in the late 20

Two lectures on demography (**6c**) are available at http://www.youtube.com/watch?v=3diw1Hu3auk (50:36) and http://www.youtube.com/watch?v=Wg3ESbyKbic (49:38).

Figure 9.20: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/171

Figure 9.21: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/172

How Do Populations Grow in Nature?

You learned above that populations can grow exponentially if conditions are ideal. While exponential growth occurs when populations move into new or unfilled environments or rebound after catastrophes, most organisms do not live in ideal conditions very long, if at all. Let's look at some data for populations growing under more realistic conditions.

Biologist Georgyi Gause studied the population growth of two species of *Paramecium* in laboratory cultures. Both species grew exponentially at first, as Malthus predicted. However, as each population increased, rates of growth slowed and eventually leveled off. Each species reached a different maximum, due to differences in size of individuals and space and nutrient needs, but both showed the same, S-shaped growth pattern. **Figures** 9.22, 9.23, and 9.24 show this growth pattern graphically as an S-shaped curve.

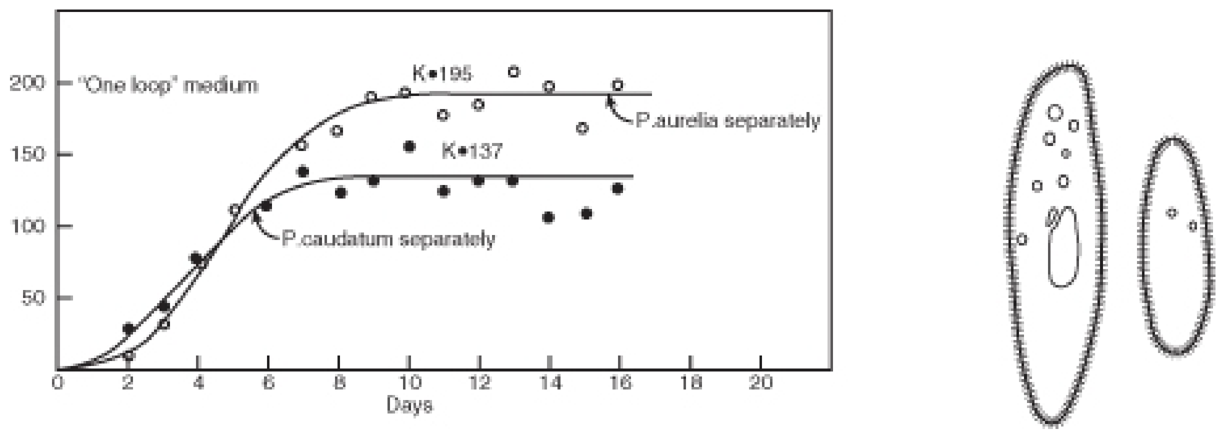

Figure 9.22: Two species of Paramecium illustrate logistic growth, with different plateaus due to differences in size and space and nutrient requirements. The growth pattern resembles and is often called an S-curve. Slow but exponential growth at low densities is followed by faster growth and then leveling.

Perhaps even more realistic is the growth of a sheep population, observed after the introduction of fourteen sheep to the island of Tasmania in 1800. Like the lab *Paramecia*, the sheep population at first grew exponentially. However, over the next 20 years, the population sharply declined by 1/3. Finally, the number of sheep increased slowly to a plateau. The general shape of the growth curve matched the S-shape of Paramecium growth, except that the sheep "overshot" their plateau at first.

As Malthus realized, no population can maintain exponential growth indefinitely. Inevitably, **limiting factors** such as reduced food supply or space lower birth rates, increase death rates, or lead to emigration, and lower the population growth rate. After reading Malthus' work in 1938, Pierre Verhulst derived a mathematical model of population growth which closely matches the S-curves observed under realistic conditions. In this **logistic (S-curve) model**, growth rate is proportional to the size of the population but also to the amount of available resources. At higher population densities, limited resources lead to competition and lower growth rates. Eventually, the growth rate declines to zero and the population becomes stable.

The logistic model describes population growth for many populations in nature. Some, like the sheep in Tasmania, "overshoot" the plateau before stabilizing, and some fluctuate wildly above and below a plateau average. A few may crash and disappear. However, the plateau itself has become a foundational concept in population biology known as **carrying capacity (K)**. Carrying capacity is the maximum population size that a particular environment can support without habitat degradation. Limiting factors determine carrying capacity, and often these interact. In the next section, we will explore in more detail the kinds of factors which restrict populations to specific carrying capacities and some adaptations that limit growth.

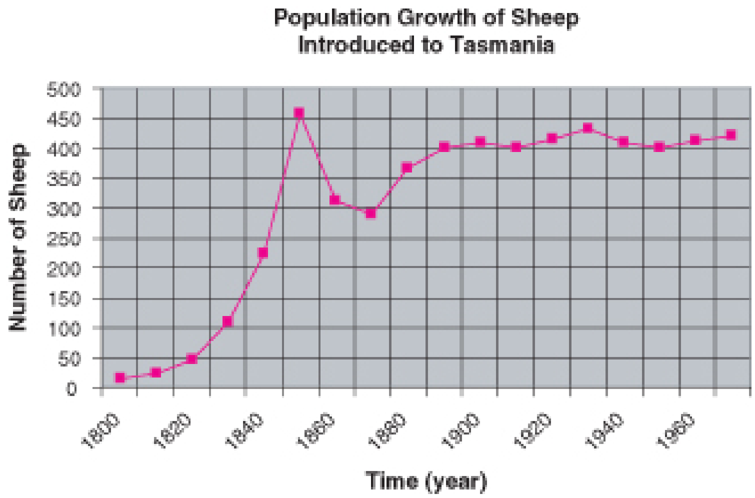

Figure 9.23: Sheep introduced to Tasmania show logistic growth, except that they overshoot their carrying capacity before stabilizing.

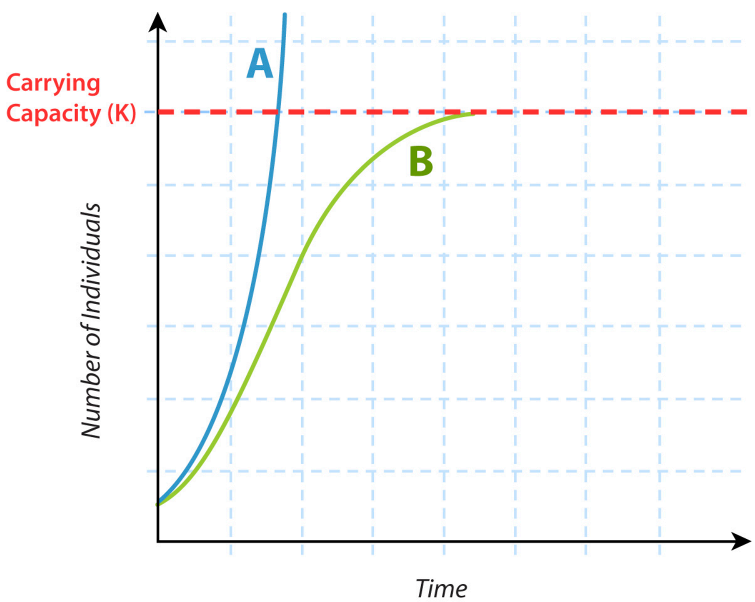

Figure 9.24: Growth of populations according to Malthus

Limits to Population Growth

A **limiting factor** is a property of a population's environment – living or nonliving – which controls the process of population growth. Biologists have identified two major types of limiting factors: Density-dependent factors and Density-independent factors.

- **Density-dependent factors** promote **intraspecific competition** – competition between members of the same population for the same resource – as the population grows and becomes more crowded. Density-dependent limiting factors have the potential to control population size. Consider food supply as an example. When population density is low, amount of food per individual is high, and birth rates are high. As density increases, food supply per individual decline and birth rates drop, causing growth rate to decline. Eventually, food shortages may lead to increased death rates and a negative growth rate, lowering population size. Lower population size means more food per individual, and the population begins to grow again, reaching or temporarily overshooting the carrying capacity. Food supply in this instance is a regulatory limiting factor, because it keeps the population at equilibrium. Density-dependent limiting factors may include:
- Light
- Water, nutrients/minerals, or oxygen
- Waste, or the ability of an ecosystem to recycle nutrients and/or waste
- Predation by predators which feed preferentially on more abundant prey
- Disease and/or parasites
- Space, with or without territorial behaviors, or nesting sites
- Temperature
- Aggressive behaviors, often combined with stress and effects on immune systems

Let's look at two examples in detail, to emphasize the importance of density-dependent regulation of growth. First, waste products build up with increasing population density. Most environments have some capacity for recycling of wastes, but sometimes rapid population growth means that natural environmental systems can't keep up. An interesting - if not completely natural - example is the growth of yeast populations through fermentation in the making of wine. Alcohol is a waste product for the yeast, even though it is the point of the process as far as we're concerned. As the yeast population grows, alcohol builds up; but alcohol is toxic – to yeast as well as to humans – and after the concentration reaches 13%, increased death rates doom the yeast population. Therefore, no naturally fermented wine contains more than 13% alcohol.

- A second density-dependent limiting factor is predation. Predators kill and eat their prey, of course, so predation increases prey death rate and can cause negative growth rates – population decline. If predators have multiple types of prey, and switch their feeding to specific prey only when they are abundant, predators may regulate prey population size. However, especially in northern climates, predators often specialize on a single prey species. Goshawks, for example, feed primarily on ruffed grouse, and Canada Lynx depend on snowshoe hares (**Figure** 9.25). If predation causes a significant decline in the prey population, starving predators may experience their own (delayed) decrease in population as a result of lower birth rates or increased death rates. The result is a **predator-prey cycle**; both populations rise and fall, with predator populations trailing prey (**Figure** 9.26).

Goshawks play the game with a little twist; when ruffed grouse populations in their Canadian conifer forest homes decline, they migrate southward. Grouse populations show ten-year cycles; note that the goshawk counts from Hawk Ridge in Duluth, Minnesota show ten-year ''invasions" which correspond to prey population lows in Canada (**Figure** 9.27).

Figure 9.25: Populations of snowshoe hare (left) and their Canada Lynx predator (right) show repeating cycles, with predator population changes trailing those of their prey.

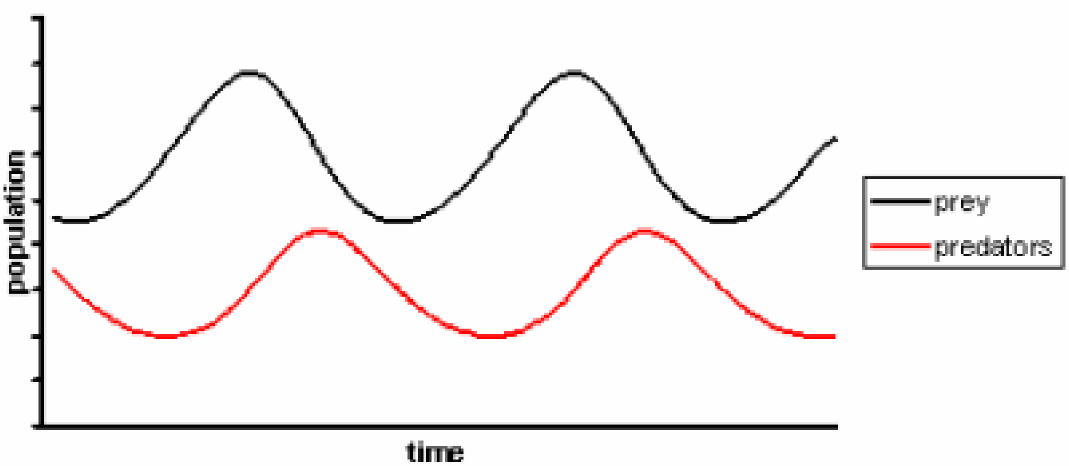

Figure 9.26: Repeating cycles of growth and decline characterize population dynamic interactions between some pairs of predator and prey species.

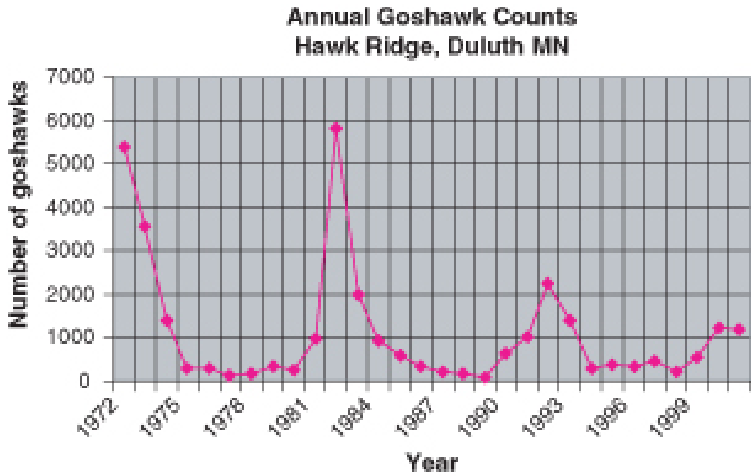

Figure 9.27: The pattern of migration of goshawks observed at Hawk Ridge in Duluth, Minnesota, shows irruptions which correspond to low points in cycles of their Canadian prey populations (ruffed grouse). Such cycles are the result of density-dependent interactions between predator and prey. Predators cause increased death rates in prey populations, especially at high prey densities. When prey populations crash as a result of predation, predators are stressed and some (such as lynx) decline. Others, such as the goshawk, irrupt southward in search of higher-density populations.

All of these factors have the potential to lower birth rates or increase death/emigration rates via increased intraspecific competition at higher population densities. Many natural populations are kept at or below carrying capacity by one or a complex interaction among several of the above limiting factors.

- **Density-independent factors** can also limit populations, but they seldom regulate populations because they act irregularly, regardless of the population's density. Populations limited by density-independent factors seldom reach carrying capacity. Weather is a good example. Agaves (Century Plants) reproduce once at the end of a long lifespan (**Figure** 9.28). The average lifespan is about 25 years rather than a full century, but an individual's lifespan depends at least in part on erratic rainfall. Agaves will reproduce only after rainfall allows sufficient growth – however long that takes. Eventually, a wet season will bring about a single episode of flowering and the production of a huge number of seeds. Their growth and eventual reproduction will, in turn, depend on erratic rainfall. The density-independent factor rainfall limits birth rate, which in turn limits growth rate, but because of its unpredictability, it cannot regulate Agave populations.

Other density-independent limiting factors include human activities:

- *Pesticides and herbicides*: For example, DDT thinned the eggshells of Peregrine Falcons, reducing their birthrates and leading to their extirpation from the eastern half of North America.
- *Habitat destruction*: Conversion of prairies and grasslands worldwide drastically reduced populations of Burrowing Owls in North America and Giant Pandas in China.

To conclude our discussion of population dynamics, let's look at two sets of adaptations related to the logistic growth curve which describe the growth of most populations. These should remind you of the survival patterns we discussed earlier in this lesson. Recall that for logistic growth, r is the **growth rate** of the population, and K is the **carrying capacity**.

- Scientists have found that species adapted to unstable or unpredictable environments are usually limited by density-independent factors to population densities considerably lower than carrying capacity.

Figure 9.28: Each Century Plant reproduces only once during its long lifespan. This strategy allows it to gather sufficient water over a number of years in an environment where rainfall is scarce and unpredictable. Then, during an especially wet season, the plant produces a huge number of seeds and dies. Does the Century Plant

Such environments favor adaptations which maximize growth rates: early maturity, small size, high numbers of small offspring, single episodes of reproduction, short life expectancy, and the ability to disperse widely. Because populations are usually far below carrying capacity, crowding is minimal, so these species invest little energy in competitive adaptations. Survivorship curves (**Figure** 9.14) are Type III, with high early death rates. Such species are said to be **r-selected** – that is, selected for rapid growth. Weed species are often *r*-selected for colonization and rapid population of disturbed or newly created habitats such as roadsides, abandoned fields, mudslides, or lava flows. Jack pine trees are *r*-selected species which "pioneer" clear areas immediately after forest fires. They grow quickly in hot, dry soils and release seeds from cones which are opened only by fire – reproducing and dispersing seeds at just the right, if unpredictable, time (**Figure** 9.29).

Figure 9.29: Jack pines show r-selected adaptations to an unpredictable (density-independent) limiting factor: fire. Cones (bottom image) open to release many tiny seeds only at high temperatures. The trees (top image) grow quickly in the open, bare areas left by forest fires, so are often called

- Whereas density-independent factors limit **r-selected species** in unpredictable environments, **K-selected species** are adapted to stable environments and regulated by density-dependent factors. Stable environments support K-selected populations at or near carrying capacity, at which point crowding leads to significant intraspecific competition. Such environments favor adaptations for efficient resource utilization which confer competitive ability. K-selected individuals often grow slowly to large size, live long, and delay but repeat reproduction of fewer offspring. They may provide extensive parental care because they can count on environmental stability and survival of these relatively few offspring. Survivorship curves resemble the Type I pattern: long life expectancy and relatively low death rates in the stable environment. Maple trees are K-selected ‘‘climax” species which grow slowly in their own shade and reproduce relatively large seeds over a number of years throughout their relatively long lifespan (**Figure** 9.30).

Figure 9.30: Maple trees show K-selected adaptations to a predictable shade environment they help to create. Maples release relatively large seeds annually, and offspring grow slowly but steadily in the shaded, rich soil of their parents. Maples experience significant intraspecific competition, and their populations tend to be limited by density-dependent factors. Because maple forests tend to persist for long periods because they can grow in their own shade, they are often called

Characteristics of r-selected and K-selected species are compared in **Table** 9.3.

Table 9.3:

	r- Selected Species	K-Selected Species
Environment	Unstable	Stable
Type of Regulating Factors	Density-independent	Density-dependent
Organism Size	Small	Large
Maturity	Early	Late
Number of Offspring	Many	Few
Energy used to make each Individual	Low	High
Average Life Expectancy	Short	Long
Number of Reproductive Events per Individual	Once	Many times
Survivorship	Type III: only a few individuals live long lives	Type I or II: most individuals live long lives

In conclusion, all populations eventually reach limits, at or below carrying capacities for the ecosystems in which they live. Some have adaptations for rapid growth, but the unpredictable environments in which they live inflict high death rates. Others live in stable environments where death rates are relatively low, but their populations are high, so individuals must spend energy on costly competitive strategies in order to gather scarce sunlight, nutrients, or water - or fight disease or predation. Many species live between these extremes, but all populations have limits.

9.3 Human Population Growth: Doomsday, Cornucopia, or Somewhere in Between?

Hundreds of stone figures measuring up to 10 meters tall and weighing up to 87 tons overlook a low-diversity grassland on Easter Island in the Pacific Ocean (**Figure** 9.31). The food sources, woody trees, and rope-yielding plants which helped to build and transport these statues over five hundred years ago are gone.

Figure 9.31: Easter Island today is a low-diversity grassland nearly devoid of the food sources, woody trees, and rope-yielding plants which helped to build and transport these 10-meter stone statues. Jared Diamond suggests that overpopulation and overexploitation of resources led to the collapse of a once-thriving Easter Island society, and that Easter Island is

Pollen analyses suggest that the island was totally forested at least until 1200 CE, but that by 1650 the forests had entirely disappeared. Middens (waste dump sites) show a sudden disappearance of sea bird and fish bones, suggesting that wood for canoes was no longer available. Sediments reveal that half of native plant species had become extinct. Later fire pits indicate the possibility of cannibalism.

Jared Diamond, in his book *Collapse: How Societies Choose to Fail or Succeed,* examines this bleak scene and other past societies and concludes that doomed civilizations share eight traits which contribute to their collapse. Seven of the eight traits are rooted in overpopulation relative to environmental carrying capacity. Diamond considers Easter Island to be ‘‘Earth writ small” – a warning that this island's environmental devastation could foreshadow a similar fate for our planet. He encourages humans to learn from earlier collapses to conserve the forest, soil, water, animal, fish, photosynthetic, atmospheric, and energy resources upon which our human lives depend. A large group of people sometimes known as ‘‘**Neo-Malthusians**” join Diamond in his belief that human population growth cannot continue without dire consequences.

Julian Simon and a group dubbed ‘‘**cornucopians**” see the human condition differently. Named for the mythical Greek ”horn of plenty” which supplied endless food and drink magically, cornucopians believe that the Earth can provide an almost limitless abundance of natural resources, that few natural limits to growth exist, and that technology can solve or overcome population-induced resource scarcity and environmental degradation. Larger human population (within an appropriate political environment) is the answer to the problems of population growth, according to Simon.

Are you, like Diamond and Malthus before him, a ‘‘doomster”? Or do you join Simon as a ‘‘boomster”? Most ‘‘doomsters” and ‘‘boomsters” share the belief that we are responsible for managing problems related to population growth. Let's use our understanding of **population** biology to study the human population. Our goal will be to shed light on the decisions we – the only species able to consider and alter our rates of birth and death – make about future population growth.

The past two lessons have shown how populations in nature grow. You have learned that all populations have the *potential* to grow **exponentially** (**J-curve** pattern of growth), but that exponential growth is limited to ideal conditions, which are rare in nature. In nature, competition for limited resources or unpredictable, density-independent limiting factors restrict populations to densities at or below carrying capacities (**S-curve** growth pattern). Some populations grow smoothly to a stable carrying capacity, but others overshoot that density and may crash before rebuilding to a relatively stable level. A few crash to extinction. In unstable environments, some populations establish cycles of population growth and decline. Unstable environments favor adaptations for rapid growth (**r-selected species**), and stable environments favor adaptations for efficient use of resources (**K-selected species**).

Where do humans fit? Are we built for growth – or conditioned for efficient use of resources? Does our growth pattern resemble a J, or an S? Are we in danger of extinction? What exactly is our "population problem," and what can we do to solve it?

Early Human Population Growth

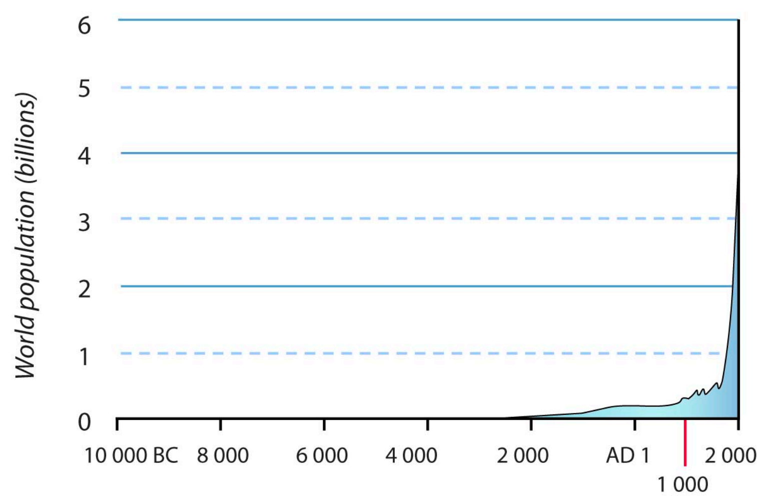

Figure 9.32: The growth of the world

Let's begin by looking at the data. Worldwide human population from 10,000 BCE through today is graphed in **Figure** 9.32. The theoretical J (exponential) and **S (logistic) growth** curves are reviewed in **Figure** 9.33. Overall, our growth resembles exponential growth (the J curve), increasing very slowly at first, but later growing at accelerating rates which show no sign of nearing carrying capacity. We appear to be *r*-selected for rapid growth; indeed, some have described humans as the most successful "weed species" Earth has ever seen as we are fast growing, rapidly dispersing, and colonize habitats from pole to pole. If Earth has a carrying capacity for humans, it is not yet visible in our growth curve – at least on this scale.

However, closer study of human population dynamics reveals more complexity. Different countries show different patterns of population growth today, and history shows varying patterns of growth across time. The history of human population growth can be divided into four stages. Today's countries show snapshot views of these stages. In this section, we will look at early human population growth.

As scientists currently understand human history, *Homo sapiens* arose about 200,000 years ago in Africa. Living as nomadic hunter-gatherers, we migrated to Eurasia and Australia about 40,000 years ago and into

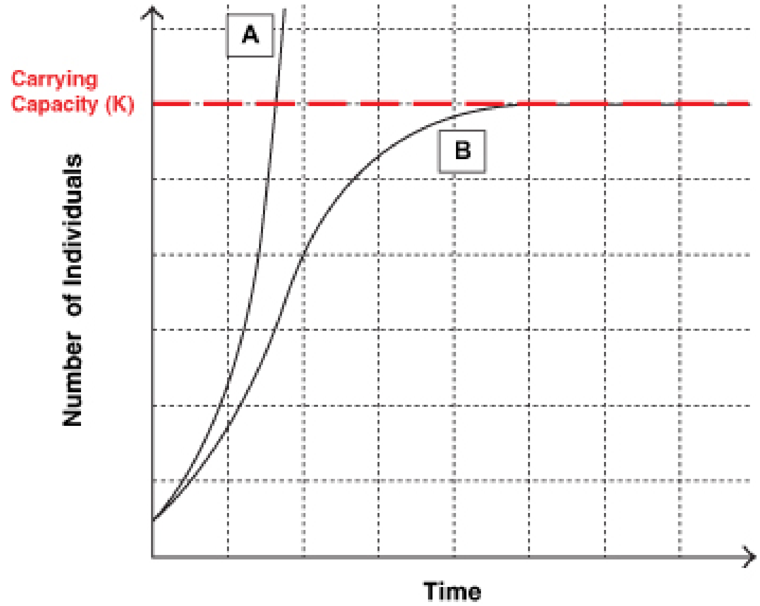

Figure 9.33: Growth of populations according to Malthus

the Americas 30,000 years later. Throughout this period, both birth rates and death rates were probably high – as much as 5%. Our human population grew slowly as we spread throughout the world, out-competing other hominid species with our apparently superior reproductive and competitive adaptations. Ice ages, warming periods, and volcanic eruptions were density-independent factors which severely limited our population growth. For example, a "supervolcanic" eruption at Toba in Sumatra 74,000 years ago covered India and Pakistan with more than 5 feet of ash, causing 6 years of nuclear winter, a thousand-year ice age, and the death of up to 99% of the humans living at the time!

With the invention of agriculture 10,000 years ago, we began to develop settled civilizations and trade. Disease associated with animal domestication and city living increased death rates, but reliable food supplies, shared childcare, and division of labor increased birth rates. These effects may have offset each other; slow and uneven growth probably continued. However, the development of agriculture, like many advances in technology, almost certainly raised carrying capacity.

Beginning about 6000 years ago, political states evolved, cooperated or competed, and sometimes waged war. Empires formed, connecting previously independent populations. In the Middle Ages, technology advanced, and the 17th century brought the Scientific Revolution. Throughout this long period of human history, death rates and birth rates continued to be high. **Density-independent factors** such as drought and the "little ice age" combined with **density-dependent factors** such as disease to keep death rates high and variable. The "black death" of the mid-fourteenth century killed as many as 75 million people worldwide and the disease is one of the very few events whose effects are visible in any graph of human population growth (**Figures** 9.32, 9.34). Birth rates continued at a high level throughout early human history. Carrying capacity rose with major advances in technology, as humans modified the environment by irrigating land, building cities, and transporting animals, plants, and products. The overall result was slow growth and a young population. By 1804 CE, the world's human population had reached 1 billion.

Demographic Transition

Major changes in human population growth began during the 18th century, but they affected different regions at different times. We will first consider Europe, and later compare Europe to other regions of

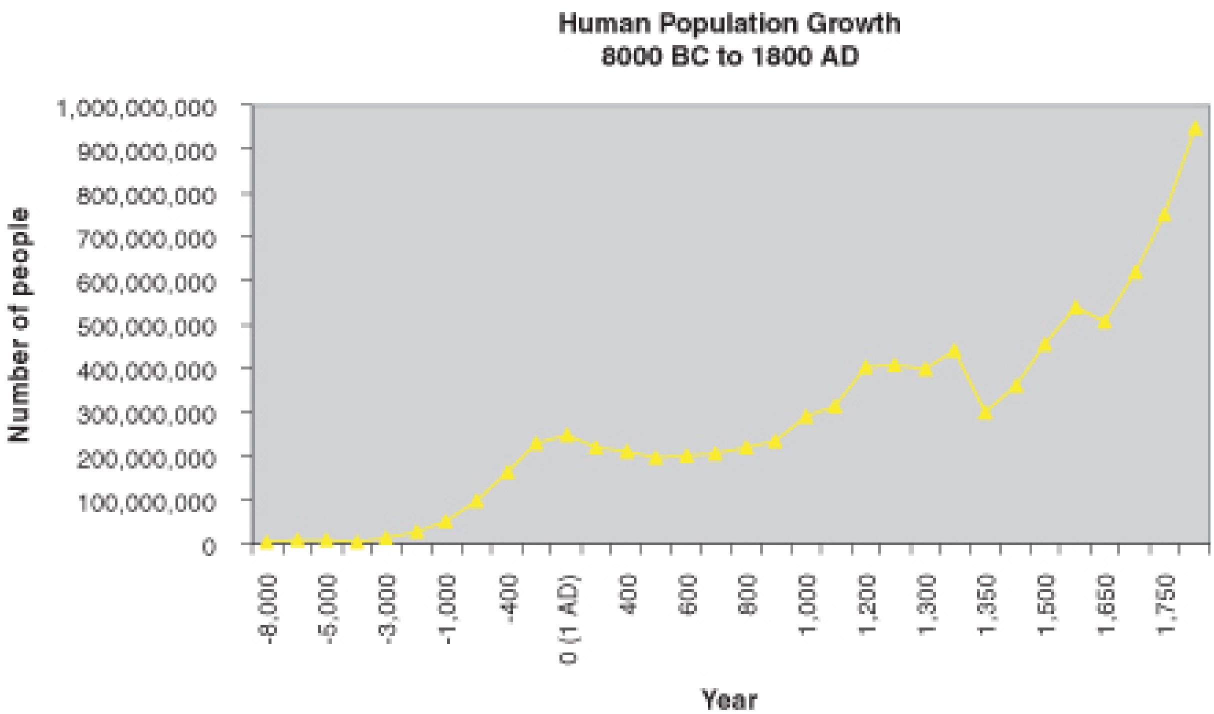

Figure 9.34: Early human populations showed slow, uneven growth. At this scale, the negative effect of increased death rate due to the

the world. In 18th century Europe, seed planters, improved ploughs, threshing machines, crop rotation, and selective breeding of animals led to major growth in food supplies, so death rates due to starvation declined. With increasing understanding of the causes of disease, people improved water supplies, sewers, and personal hygiene – and lowered death rates even more. The Industrial Revolution of the 19th century developed new sources of energy, such as coal and electricity. These further increased the efficiency of new agricultural machines and promoted the development of new forms of transportation, mainly railroads, which improved distribution of food. Death rates fell – particularly for those 5 to 10 years of age, allowing many more children to survive to reproduce. The pattern of human survivorship shifted toward a Type III curve.

Although death rates fell, birth rates remained at earlier levels. The gap between birth and death rates increased, and population growth began to accelerate (remember that $r = b - d$). Although this change did not happen uniformly throughout the world, it was soon reflected in world population levels: it took 200,000 years for the human population to grow to 1 billion, but only 123 years to grow to 2 billion!

Demographic transition theory holds that human populations pass through four stages of growth (**Figure** 9.35).

- Early human history, with its slow, uneven growth maintained by high rates of birth and death, illustrates Stage 1 (**Figure** 9.34, but compare to section "1" of **Figure** 9.35).
- Stage 2, just discussed for Europe, involves a significant drop in death rate *not matched by an increase in birth rate*, resulting in an increasingly rapid rise in population – exponential growth.
- In Stage 3, according to the theory, changes in technology and society lead to a decline in birth rate:

1. The decline in child mortality and improvement in agriculture leads rural families to realize they no longer need to have as many children.
2. Agricultural improvements shift more people to urban areas and reduce the need for children.

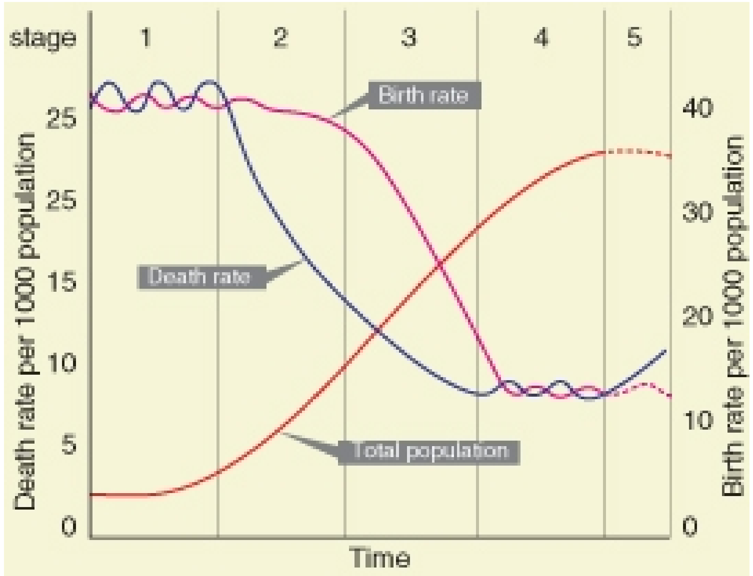

Figure 9.35: Demographic transition theory proposes that human populations pass through four or five predictable stages of population growth. The 1st and 4th stages are relatively stable, in the first stage because b and d are both high, and in the last because b and d are both low. The key to the theory (disputed by some) is this: once death rates fall due to industrialization and technology, birth rates will follow (the Transition, Stages 2 and 3). Because the theory is based on observations of developed countries, some people dispute its universality.

3. Compulsory education removes children from the work force but adds to the cost of raising them.
4. Increasing education and employment of women reduces their time for and interest in having children.
5. Birth control methods expand.
6. Later marriage and delayed childbearing further lower birth rate.

Eventually, according to demographic transition theory, falling birth rates approach already-diminished death rates, and population growth begins to level off.

- In Stage 4, birth rates equal death rates, $r =$ zero, and populations become stable.

This somewhat idealistic theory suggests that societies pass through predictable changes which lead to population growth patterns resembling the logistic or S curve. As we have seen (Figure 1), world population growth does not (yet?) show Stages 3 or 4. However, individual countries appear to be at different stages along the continuum; some have reached Stage 4 and a few even require the addition of a 5th stage.

Recent Population Growth

Death rates have fallen throughout the world, so that no country today is considered to remain in Stage 1. Countries appear to vary with respect to the timing of Stages 2 and 3. Many less developed countries remain in Stage 2, including Yemen, Afghanistan, Bhutan, Laos, and part of Sub-Saharan Africa.

Angola's age structure (**Figure** 9.36) reveals accelerating Stage 2 growth. Widest at its base, the structure indicates many youths who will survive to reproduce at their parents' high **fertility** rates because death rates are declining. Some countries, particularly those in regions of Africa which have been devastated by AIDS, appear stalled in Stage 2 due to disease and stagnant development. The demographic transition model may not prove to fit population growth in developing countries. Poor, low-income people in undeveloped countries have the highest birth rates. If demographic transition requires wealth and education, the world's unequal distribution of development and resources may mean that these high birth rates will merely maintain exponential growth, rather than precipitate the social change associated with industrialization.

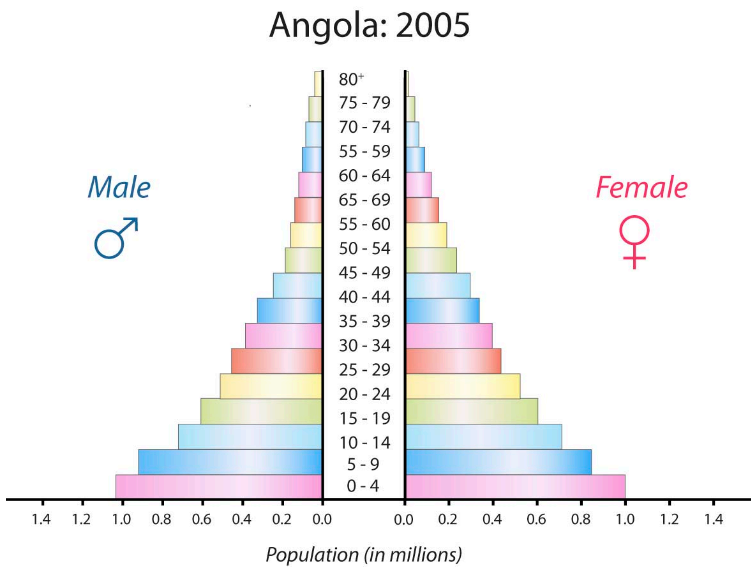

Figure 9.36: Angola

However, many countries appear to have begun the shift to Stage 3. Fertility rates have dropped 40% throughout much of South America, the Middle East, and the Pacific Islands. Countries such as India, Bangladesh, and Zimbabwe have lowered birth rates between 25-40%, and others such as Pakistan, Saudi Arabia, and Haiti have reduced fertility to 10-25% of earlier rates. Populations in most of these countries are beginning to level off, although resistance to change in the social factors which reduce birthrate may delay or prevent this response. Ecologist Garrett Hardin has pointed out that voluntary birth control selects against people who use it; by itself, voluntary control is unlikely to limit population growth.

High levels of industrialization and development have led to **replacement** (or lower) **fertility rates** in most of Europe, the United States, Canada, Australia, Brazil, China, and Thailand. China, Brazil, and Thailand passed through demographic transition extremely rapidly due to rapid economic and social changes. Replacement fertility includes 2 children to replace parents and a fraction of a child to make up for early mortality and at-birth sex ratio differences. Because mortality rates vary, replacement fertility rate ranges from 2.5 to 3.3 in poor countries, but averages 2.1 in developed countries. Globally, replacement fertility is 2.33 children per woman. In Stage 3 countries, populations will eventually stabilize if replacement fertility continues. However, many - including the US – continue to grow rapidly due to the "youth bulges" of exponential Stage 2 growth. The age structures of China and the US (**Figure** 9.37) show demographic transition, but also youth bulges which will mean continuing growth for some time.

Some countries have lowered birthrates below death rates so that r is actually negative. Japan, Germany, Italy, Spain, Portugal, and Greece are not producing enough children to replace their parents; populations in some of the southern European countries have already begun to decline. Top-heavy age structures for Spain and Japan are shown in **Figure** 9.38. In countries such as Russia, negative growth emerged suddenly from economic and political crises which caused emigration, declining fertility, and increased male mortality, rather than from development and wealth as the transition model predicts. Negative growth rates pose economic threats: growth-dependent industries decline, and the burden of a large aging, economically dependent population falls on a smaller group of young workers. These shrinking population conditions are sometimes referred to as **Stage 5** of the demographic transition.

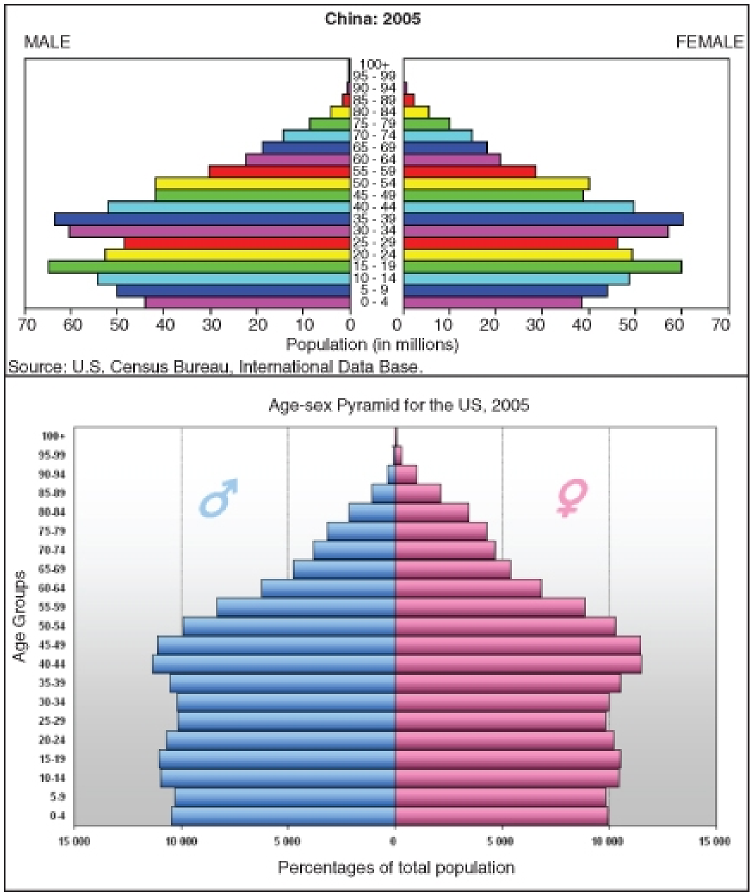

Figure 9.37: Population pyramids for China (above) and the U.S. (below) show decreased birth rates which suggest they have reached Stage 3 of the demographic transition model. Both countries show a population bulge remaining from Stage 2 exponential growth, so populations will continue to grow for a number of years. Eventually, if birth rates remain at replacement levels, populations will stabilize in Stage 4.

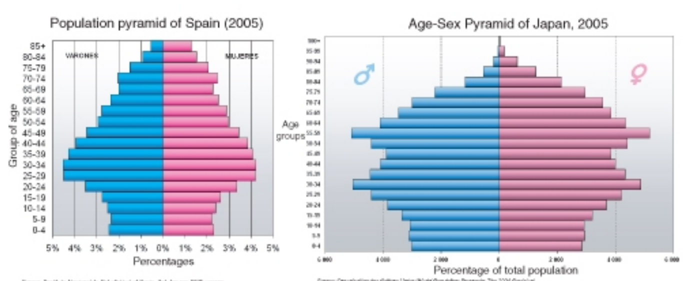

Figure 9.38: The top-heavy age structures for Spain and Japan show declining populations due to birth rates which have fallen below already-low death rates. Unless significant immigration occurs, these countries may suffer negative economic effects, such as decline in growth-dependent industries. The burden of a large aging, economically dependent population may fall on a smaller group of young workers.

Future Population Growth: Does Earth Have a Carrying Capacity for Humans?

As of September 2007, the world's human population stood at about 6.7 billion, growing by 211,090 people each day. Historically, we didn't hit the one-billion mark until 1804 (having begun 200,000 years earlier), but we needed just 12 years to grow by our last billion. Projections by the United Nations and the U.S. Census Bureau predict that by 2050, Earth will host 9.4 billion people; other estimates project that the earth will host 10 to 11 billion people by 2050.


See http://www.youtube.com/watch?v=4BbkQiQyaYc (7:31) for an animation of world population growth.

Figure 9.39: (Watch Youtube Video)
http://www.ck12.org/flexbook/embed/view/648

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Cornucopians welcome such growth, believing more people are better for technology and innovation. The demographic transition model predicts that when all nations are industrialized, the human population will eventually reach a stable level – a carrying capacity of sorts. However, many scientists believe that humans have already overshot the carrying capacity of Earth for our unique levels of resource exploitation and habitat alteration. They and other Neo-Malthusians predict that resource depletion and environmental degradation will eventually lead to famine, epidemics, or war – a Malthusian crisis.

Does Earth have a carrying capacity for humans? Recall that carrying capacity is the maximum population size that a particular environment can support without habitat degradation. Ideally, carrying capacity matches population size to resource availability. Although the human population is clearly continuing to grow, many scientists believe that we over-consume resources and exceed the environment's capacity to cycle nutrients and process waste. They believe that multiple factors will contribute to a crisis in which disease, starvation, or global conflict will cause a population crash or even extinction:

- Our current *agricultural system*, globally transformed by the **Green Revolution** of the mid-20th century, depends heavily on nonrenewable fossil fuels for fertilizers, pesticides, and irrigation. Ecologist and agriculturalist David Pimentel predicts that to avert disaster, the U.S. must reduce its population to a maximum of 200 million (we are now above 300 million – see the "pop clock" **Figure** 9.40), and the world population must drop to 1/3 its current level. Distribution of food has long been a problem and today has some rather ironic consequences: A 2006 MSNBC report claimed, "There are an estimated 800 million undernourished people and more than a billion considered overweight worldwide."

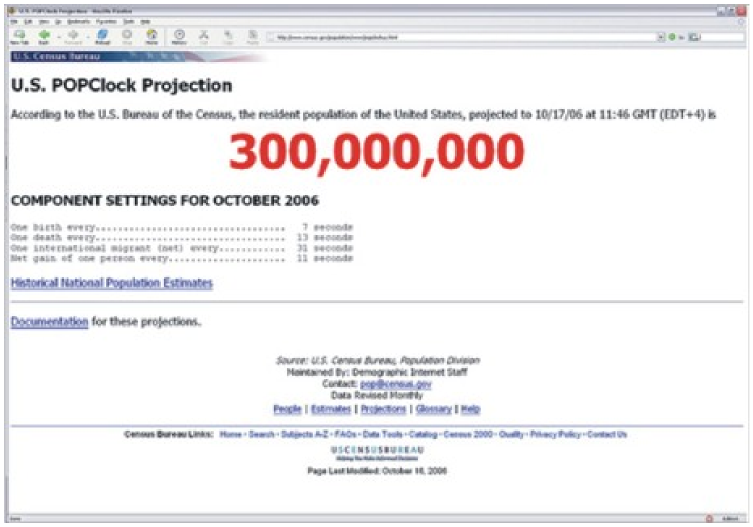


Figure 9.40: The U.S. population passed 300 million on October 17, 2006. Agriculturalist David Pimentel believes the U.S. must lower its population by 1/3 to prevent a crisis caused by inability to continue our fossil fuel-dependent agricultural practices. U.S. and World Population Clocks are maintained by the U.S. Census Bureau online at:

- Both developing and developed countries depend almost entirely on *petroleum* to fuel industrialization and transportation, as well as agriculture. In 1956, geophysicist Marion Hubbert predicted that world oil production would peak about half a century into the future and then decline, initiating a global crisis. Predictions about the consequences of **Peak Oil** range from successful development of alternative fuels, to collapse of the global industrialized economy, to intense nationalism and war. Some analysts, such as energy banker Matthew Simmons, believe that the Peak has already occurred (**Figure** 9.41). Others, like energy industry consultants Wood McKenzie, believe we will not reach the peak for another ten years. The difference does not seem significant, but ten years would allow more time for development of alternative fuels and institution of conservation measures.

- **Fresh water supplies** are declining due to pollution and overuse. According to the United Nations, 2.6 billion people lack water for sanitation, and 1.1 billion have inadequate supplies of safe drinking water. Irrigation and overuse have seriously reduced groundwater supplies, and water pollution threatens biodiversity as well as human sources. Waterborne diseases and lack of water for sanitation cause up to 80% of human illness. Growing populations, of course, will worsen this water crisis.

- **Habitat destruction** due to agriculture, urban sprawl, and mining is the number one cause of extinction today, precipitating a biodiversity crisis. The World Resources Institute estimates that agriculture has displaced 1/3 of all temperate and tropical forests and &frac;14; of all grasslands; in the U.S., less than 2% of native prairie ecosystems remain. Stephen Hawking calculates that continuation of the last 200 years' rate of population growth would have us all standing shoulder-to-shoulder, literally.

- Burning fossil fuels has brought about **atmospheric change**.

Sulfur and nitrogen emissions cause acid rain, which destroys fish, lakes, forests, and limestone structures. CO_2 emissions lead to global warming. Earth's surface air temperatures have risen 0.74°C (1.33°F) during

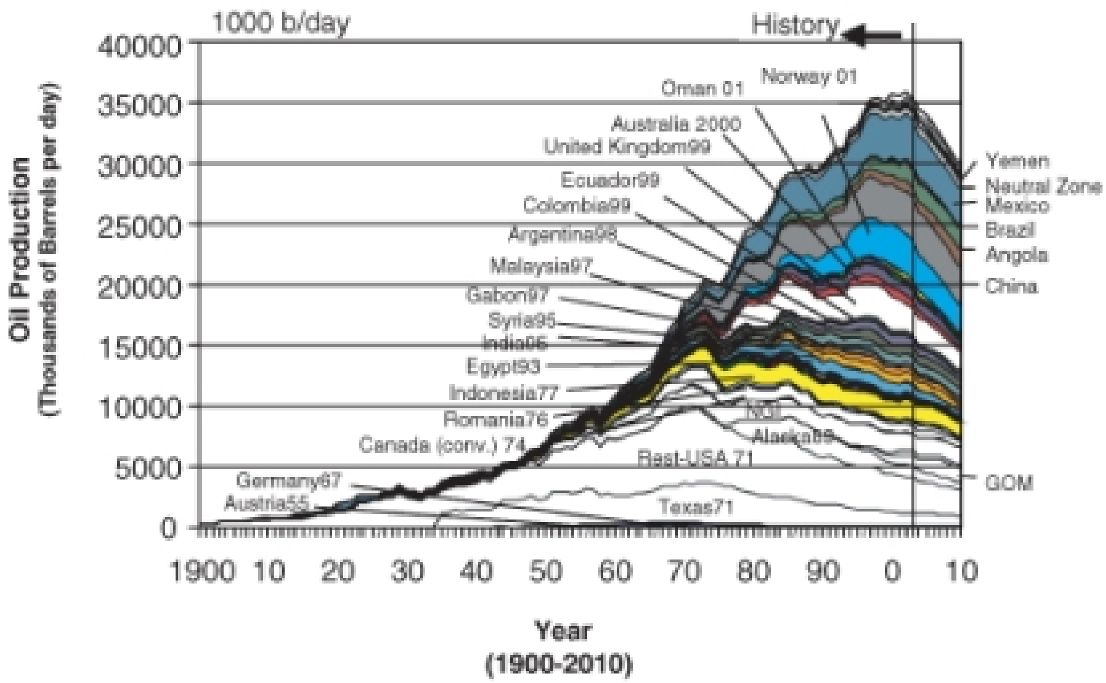


Figure 9.41: Oil production outside OPEC and former Soviet Union countries has already peaked, according to oil industry data bases for 2003 and 2004.

the last 100 years, and will continue to rise by 1.1 to 6.4 °C (2.0 to 11.5 °F) by 2100, according to the Intergovernmental Panel on Climate Change (IPCC).

Food, oil, water, land, and air crises support the idea that our human population has already grown beyond carrying capacity with respect to environmental degradation. As world population continues to grow, what can we do to avert famine, disease, or war? How can we prevent a crash? What should be our goal?

Urban Growth & Sprawl

Cities came in to existence as human population on Earth began to increase to large numbers due to our ability to cultivate large amounts of food with agricultural innovation. See read these websites on human populations:

1. http://www.prb.org/Educators/TeachersGuides/HumanPopulation/PopulationGrowth/QuestionAnswer.aspx
2. http://www.actionbioscience.org/environment/hinrichsen_robey.html

Urbanization is defined as the movement of people from the countryside to towns and cities

- Urban areas are sinks for resources and cannot function without goods and materials from other areas.
- Undeveloped land must be left intact so that ecosystems can function, provide ecosystem services (e.g. purify air and water) and serve as wildlife habitat.

In today's world, 20 cities are home to more than 10 million residents.

- Tokyo, Japan has 35 million residents.
- New York City has 18.7 million residents.

Location of Cities

- Climate, topography, and waterways help determine urban growth.
- Many well-located cities are linchpins in trading networks.
  - They are located near rivers, coasts, railroads or highways
  - They utilize resources transported from agricultural regions near and far
  - They utilize other material and products (e.g. wood, metals) shipped from near and distant markets.

In developing nations, people are mostly moving to cities because

- there is less need for farm labor due to industrialization
- of the perception that there are more jobs in the cities
- of the attraction of the same jobs paying more in the cities compared to outside the city
- wars, conflict, and ecological degradation in rural places drive people to cities.

In developed nations, city dwellers face overcrowding, pollution, and poverty because the city's economic growth does not match its population growth (i.e. more people than jobs available).

- Especially in developed countries, there is overall movement from rural places to the suburbs, which has resulted in urban sprawl.

- Read about urban sprawl in this website: http://svs.gsfc.nasa.gov/stories/AAAS/
- Generally a person living in the city has a smaller ecological footprint than a person living in the suburbs. This is because the city dweller has a smaller apartment, does not own a car since most cities have good public transport networks.
- Urban sprawl causes a lot of environmental problems. Read about urban sprawl related environmental problems in these websites:

1. http://www.nrdc.org/cities/smartGrowth/rpave.asp
2. http://www.riverdeep.net/current/2000/04/front.270400.sprawl.jhtml
3. http://faculty.washington.edu/jbs/itrans/sprawl.htm

Solutions: Populations and Sustainable Growth

Fortunately, individuals, organizations, and governments are beginning to address these problems. The concept of **sustainability** as a goal for human activities may hold promise for economic, social, and environmental decision-making. Although the term is recent, the concept is clearly expressed in the Great Law of the Iroquois Confederacy:

"In our every deliberation we must consider the impact of our decisions on the next seven generations." http://en.wikiquote.org/wiki/Native_American_proverbs

A sustainable activity or state can be maintained indefinitely, without compromising resources for the future. Sustainability of products and services considers complete life cycles – raw materials, manufacturing, transportation/distribution, use and re-use, maintenance, recycling and ultimate disposal. All phases must address conservation of natural and human resources and also biodiversity. Many people believe current population and lifestyles are not sustainable. Unequal distribution of resources suggests that developing countries may accelerate pressure on resources in order to improve their own lifestyles.

A preliminary tool for estimating sustainability is an **ecological footprint** analysis. Your ecological footprint is the amount of land area you would need to sustain your current lifestyle. Footprint analysis considers the resources you consume and the pollution you generate, and then calculates the amount of land which would be needed to produce equivalent *renewable* resources and process associated with waste. Air, land, water, food, and energy resources are all incorporated into the model. You can estimate your own footprint online (see Links at the end of the lesson) and compare it to that of countries throughout the world (**Figure** 9.42). Note that the average U.S. footprint is 12 times that of India, 24 times that of Somalia, and 4.4 times the world average. The last figure is worth expressing in another way: to provide everyone alive today with our western lifestyle, we'd need 4 or 5 backup planets.

To date, there is no overall agreement on a carrying capacity of Earth for humans, but many people are concerned about population growth, resource depletion and environmental degradation. Joel E. Cohen, in his book *How many people can the earth support*? summarizes three potential responses to the ‘‘population problem" identified at the beginning of the chapter. All three can contribute to the ultimate solution.

1. ‘‘*Make a bigger pie.*" Use technology and innovation to create, conserve, and distribute resources.
2. ‘‘*Put fewer forks on the table.*" Through birth control and cultural change, reduce both population size and lifestyle expectations.
3. ‘‘*Teach better manners.*" Transform political and social structures toward the goal of social justice.

The human population, like all populations, has the capacity to reproduce exponentially and yet must live within a finite world. Unique among animals, however, we can utilize technology, cultural planning, and

Country	Ecological footprint (global hectares per person)
Worldwide	2.2
Africa	1.1
Australia	6.6
Canada	7.6
China	1.6
European Union	4.8
Findhorn, Scotland, Ecovillage	2.56
Haiti	0.6
India	0.8
Japan	4.4
United States	9.6
Somalia	0.4

Figure 9.42: Ecological footprints measure the amount of land area required to sustain (produce replacement resources and assimilate waste) particular lifestyles. Note the 24-fold difference between citizens of Somalia and those of the US. One U.S. acre is equal to 0.405 hectares.

values in decisions which influence our future welfare. Which tools would you choose? What decisions will you help to make?

Smart Cities

Various strategies are needed to reduce urban sprawl and create cities that are sustainable and pleasant to live in

- City (urban) planning: attempts to design cities to maximize their efficiency, functionality, and beauty
- Regional planning: deals with same issues as city planning, but with broader geographic scales that must coordinate with multiple municipal governments

A "Smart city" is one that is designed with the following traits;

- efficient in public transportation so that people do not need to own cars to move around
- intelligent use of land through placement of important service infrastructures (e.g. banks, post offices) near homes
- designed with quality of life of city dwellers in mind (e.g. green spaces, sanitation)
- innovative governance to ensure efficient use of resources, waste management and maintain quality of life (e.g. control traffic volume to reduce air pollution)
- Read about smart cities from these sites:
  - http://www.financialpost.com/executive/smart-shift/story.html?id=2146219&lpos=fp
  - http://architecture.suite101.com/article.cfm/urban_planning_with_smart_growth_principles
  - Check out the National Geographic website that shows you some ideas for a smart city: http://www.national flash.html, and click on "Explore a new urbanist neighborhood"
  - In pictures: The world's smartest cities http://www.forbes.com/2009/12/03/infrastructure-economy-urban-opinions-columnists-smart-cities-09-joel-kotkin.html

9.4 End of Chapter Review & Resources

Chapter Summary

Historic concern with overpopulation includes ancient Greek delay of marriage, Malthus' predictions of a resource crisis, and Darwin's use of exponential growth in his theory of natural selection. The study of the biology of natural populations can shed light on human population issues. In biology, a population is a group of organisms of a single species living within a certain area. Population size, the total number of individuals, is important for understanding endangered or threatened species, but population density is often more useful for comparing populations across time or space. Minimum Viable Population (MVP) and Population Viability Analysis (PVA) use extensive field data to predict best management practices for a particular species in conservation biology. Double bar graph population pyramids show proportions of males and females within age groups. Population pyramids which have wide bases indicate high birth rates and probable population growth, and decreases from one age group to the next indicate death rates and (overall) life expectancy. Delaying reproduction or increasing age to sexual maturity can decrease population growth rate, even if fertility levels remain the same. Patchy habitat distribution results in patchy distribution of a population throughout its boundaries. Dispersion of a population within its boundaries depends on intraspecies competition or cooperation. Survivorship curves show the number of individuals which survive (on a power-of-ten scale) at each age level. Populations have the potential to grow exponentially, at least under ideal conditions. Exponential growth begins with slow growth, but as population increases, growth rate increases. J-curves depict the pattern of exponential population growth. If birth rate (plus immigration) exceeds death rate (plus emigration), a population grows. If death rate exceeds birth rate, the population declines. And if birth rate and death rate are in equilibrium, growth rate is zero and the population remains stable. Dispersal moves offspring away from parents, reducing intraspecific competition. Migration, seasonal movement of populations, can affect all four components of population growth rate. Regular wandering behavior (nomadism) adapts specific populations to fluctuating food supplies. Irruption, range expansion, and colonization. A limiting factor is a property of a population's environment which restricts population growth. Density-dependent limiting factors lower birth rates or increase death/emigration rates via increased intraspecific competition at higher population densities. Many natural populations are kept at or below carrying capacity by one or a complex interaction among several density-dependent limiting factors, such as competition, predation, or disease. Density-independent factors, such as rainfall, drought, or pollution, can also limit populations, but they seldom regulate populations because they act irregularly, regardless of the population's density. Cycles of growth and decline limit some predator and prey populations. Density-independent factors limit *r*-selected species in unpredictable environments, while K-selected species are adapted to stable environments and regulated by density-dependent factors.

According to Neo-Malthusians, the worldwide human population may have already passed Earth's carrying capacity in terms of environmental degradation, resource depletion, and unbalanced distribution of food, wealth, and development. More people will increase the danger of famine or war. According to the cornucopians, technology and innovation can solve any problems which arise due to human population growth. The more people, the better. The demographic transition model suggests that human populations pass through four stages of population growth. Despite recent declines in birthrate in some developed countries, the human population will continue to increase at least until a peak in 2050 of 9.4 billion people or more. Many scientists believe that we humans have already overshot the carrying capacity of Earth if resource exploitation and habitat alteration are considered. The concept of sustainability may hold promise for economic, social, and environmental decisions. A tool for estimating sustainability is the ecological footprint. Five factors which many believe already limit sustainable human population size are:

1. Agricultural dependence on nonrenewable fossil fuels for fertilizers, pesticides, and irrigation.

2. Dependence of industry and transportation on a finite fossil fuel supply, which has already peaked.
3. Decline in freshwater resources due to pollution and overuse.
4. Habitat destruction due to urban sprawl and agriculture, and a consequent biodiversity crisis.
5. Atmospheric changes such as acid rain and global warming – both consequences of increased fossil fuel burning.

Review Questions

1. Compare the cornucopian perspective on human population growth to the Malthus' (sometimes called the Neo-Malthusian) view.
2. (If false, restate to make true.) Human concern about overpopulation is a recent phenomenon.
3. Define a biological population.
4. Define and compare the importance of population size vs. population density.
5. Explain how conservation biologists use Minimum Viable Population (MVP) and Population Viability Analysis (PVA).
6. How does patchy distribution differ from dispersion?
7. What types of information do population pyramids show? What kinds of inferences can you make using variations in population pyramid shape?
8. How does delaying reproduction affect population size, even if fertility remains constant?
9. Describe the three types of survivorship curves and the reproductive strategies they illustrate.
10. Apply what you have learned so far about population biology to your current understanding of human populations. Note: we will explore human populations in detail in a future lesson, so accept that your current understanding may be incomplete!
11. Explain Malthus' ideas about population growth and their significance to evolutionary theory.
12. Compare exponential(J-curve)growth to logistic(S-curve)growth, and explain the conditions under which each occurs in nature.
13. Summarize the equation for population growth rate, and explain each factor.
14. Compare survival and reproduction in *altricial* species to the same factors for *precocial* species.
15. How might delaying age of childbirth prevent the need to limit family size, as China has done?
16. Give examples of dispersal and migration, and how they affect populations.
17. Define carrying capacity and explain its importance to population growth.
18. Compare and contrast density-dependent and density-independent limiting factors.
19. Relate predator-prey cycles to density-dependent population control.
20. Compare and contrast the adaptations and environmental characteristics typical of r-selected species to those of K-selected species
21. Describe the *overall* pattern of human population growth, beginning with our origins 200,000 years ago and compare it to the exponential and logistic models.
22. Compare the factors that influenced human population growth up to the first 1 billion mark to those which controlled growth of the last billion.
23. Summarize the 5 stages of the demographic transition model in terms of *b, d,* and *r.*
24. Explain the problems with the original, four-stage demographic transition model of human population growth. Give examples of each.
25. Explain why replacement fertility must exceed 2 children per female.
26. Use the "pop clock" links at the end of the chapter to look up the current US and world populations. Compare these to predictions for 2050 made by the UN and U.S. Census Bureau. Why do many people consider these numbers to be above Earth's carrying capacity?
27. Summarize 5 environmental effects of human activity which may act as limiting factors for population growth. How many of these relate to our use of fossil fuels, and why is this a problem?
28. Explain how ecological footprints measure sustainability, and compare them for developed and un-

developed nations.

29. Explain what Joel E. Cohen meant by suggesting that "a bigger pie," "fewer forks," and "manners" are needed to address the problems of overpopulation.
30. Consider what you know about resource limitations, population distribution, levels of consumption, technology, poverty, economics, political realities, religious views, and different human perspectives on the earth. Choose and describe 3 changes you believe would be most successful in solving the problems of worldwide population growth – and 3 changes you believe would be least successful. Support each change with reasons why you think it would be more or less effective.

Further Reading / Supplemental Links

- http://www.estrellamountain.edu/faculty/farabee/biobk/BioBookpopecol.html
- http://www.geography.learnontheinternet.co.uk/topics/popn1.html
- http://www.census.gov/ipc/www/idb/faq.html
- http://www.biologicaldiversity.org/swcbd/species/orca/pva.pdf
- http://nationalzoo.si.edu/ConservationAndScience/EndangeredSpecies/PopViability/default.cfm
- http://www.estrellamountain.edu/faculty/farabee/biobk/BioBookpopecol.html
- http://www.geography.learnontheinternet.co.uk/topics/popn1.html
- http://curriculum.calstatela.edu/courses/builders/lessons/less/biomes/breeding.html
- http://www.bestfootforward.com/
- http://www.footprintnetwork.org/gfn_sub.php?content=footprint_overview
- http://www.panda.org/news_facts/publications/living_planet_report/index.cfm
- http://www.worldchanging.com/archives/006904.html
- http://lca.jrc.ec.europa.eu/lcainfohub/introduction.vm
- http://www.ilea.org/leaf/richard2002.html
- Joel E. Cohen, *How Many People Can the Earth Support?* Norton, 532 pp, 1995.
- http://www.bradshawfoundation.com/journey
- http://desip.igc.org/mapanim.html
- http://www.eoearth.org/article/Human_population_explosion
- http://www.globalchange.umich.edu/globalchange2/current/lectures/human_pop/human_pop.html
- http://www.census.gov/main/www/popclock.html
- http://www.bestfootforward.com/
- http://www.footprintnetwork.org/gfn_sub.php?content=footprint_overview
- http://www.panda.org/news_facts/publications/living_planet_report/index.cfm
- http://www.worldchanging.com/archives/006904.html
- http://lca.jrc.ec.europa.eu/lcainfohub/introduction.vm
- http://www.ilea.org/leaf/richard2002.html

Vocabulary to Know

- altricial - Refers to a pattern of growth and development in organisms which are incapable of moving around on their own soon after hatching or being born.
- age at maturity - The age at which individuals (sometimes considered only for females) become able to reproduce.
- age-sex structure - A graphical depiction of proportions of males and females across all age groups within a population; also depicted as a population pyramid.
- birth rate (b) - Number of births within a population or subgroup per unit time; in human demography, the number of childbirths per 1000 people per year.

- carrying capacity (k) - The maximum population size that a particular environment can support without habitat degradation.
- colonization - Movement of a population into a newly created or newly found area.
- cornucopian - A person who believes that people and markets will find solutions to any problems presented by overpopulation.
- death rate (d) - Number of deaths within a population or subgroup per unit time; in human demography, the number of deaths per 1000 people per year.
- demographic transition theory - Theory that proposes that human populations pass through 4 or 5 predictable stages of population growth.
- density-dependent factor - Factor which has the potential to control population size because its effects are proportional to population density.
- density-independent factor - Factor which may affect population size or density but cannot control it.
- dispersal - Movement of offspring away from parents, resulting in reduced competition within the population and more effective colonization of suitable habitat.
- dispersion - The pattern of spacing among individuals within a population – clumped (clustered or grouped), uniform (evenly spaced), or random (no discernible pattern).
- ecological footprint - The amount of land area needed to sustain a particular lifestyle, matching its resource consumption and pollution to necessary renewable resource production and waste assimilation.
- emigration (e) - Movement of individuals out of a population's range.
- exponential model (geometric or J-curve) - A model of population growth which assumes that growth rate increases as population size increases.
- immigration (i) - Movement of individuals into a population's range from other areas.
- intraspecific competition - Competition between members of the same population for the same resource.
- irruption (invasion) - Irregular movements, often caused by food source failures.
- K-selected species - A species which has adaptations which maximize efficient utilization of resources, conferring competitive strength near or at carrying capacity.
- life expectancy - Average survival time for individuals within a population.
- limiting factor - A property of a population's environment – living or nonliving – which controls the process of population growth.
- logistic (S-curve) - A model of population growth which assumes that the rate of growth is proportional to both population size and availability of resources.
- migration - The direct, often seasonal movement of a species or population.
- minimum viable population - The smallest number of individuals which can exist without extinction due to chance variations in reproduction, genetics, or environment.
- Neo-Malthusians - Individuals who believe that human population growth cannot continue without dire consequences.
- nomadism - Regular, wide-ranging wandering behavior, which allows some species to compensate for fluctuating food supplies.
- overpopulation - A condition in which the number of individuals in a population exceeds the carrying capacity of their environment.
- population - A group of organisms of a single species living within a certain area.
- population density - The number of organisms per unit area or volume.
- population dynamics - Changes in population size and structure.
- population growth rate (r) - The change in population size per member of the population per unit time.
- population viability analysis - A model of interaction between a species and the resources on which it depends used in conservation biology.

- precocial - Refers to species in which the young are relatively mature and mobile from the moment of birth or hatching.
- predator-prey cycle - Regular, repeating increases and decreases in a prey population followed by corresponding changes in its predator's population.
- r-selected species - Species which has adaptations which maximize growth rate, r.
- range expansion - The gradual extension of a population beyond its original boundaries.
- replacement fertility - The number of births per female required to maintain current population levels; includes 2 children to replace the parents and a fraction of a child extra to make up for early mortality and sex ratio differences at birth.
- survivorship curve - Graph which shows the number of all individuals still living (in powers of 10, on the Y-axis) at each age (on the X-axis).

Chapter 10

The Biodiversity Crisis

10.1 Introduction

Introduction

Humans, like all species, depend on certain natural resources for survival. We depend on land and soils to grow crops, which transform solar energy into food. We use the Earth's freshwater lakes, rivers, and groundwater for drinking. We rely on the atmosphere to provide us with oxygen and to shield us from radiation. We rely on Earth's biodiversity for food, clothing, and medicines. We utilize all of the ''basic four" (biodiversity, land, water, air) for recycling of nutrients and disposal of waste. Natural ecosystems, as Odum suggests, provide services for all species: they maintain soil, renew the atmosphere, replenish freshwater supplies, dispose of wastes, and recycle nutrients. In our dependence on these services, we are like all other species.

Yet in many ways, we do not behave like other species. We supplement food and animal energy with fossil fuel energy. We harvest natural resources to exhaustion, and produce waste beyond levels that the Earth can process. We alter biodiversity, land, water, air and fossil fuels beyond nature's ability to repair. As you learned in your study of population biology, our population has grown beyond Earth's carrying capacity, compounding problems of resource use and waste disposal. Only recently have we learned to appreciate the full value of these resources – and the potential for harm from our own activities. Our economics have not caught up to our relatively new understanding: we do not yet pay the costs of maintaining all of ''nature's services."

This lesson will explore biodiversity – the ''millions of organisms and hundreds of processes - operating to maintain a livable environment." The topic is timely, critical, and colorful: you will encounter warnings of a Biodiversity Crisis and the Sixth Extinction (created by the Anthropocene), and species identified as ''an Elvis taxon" or ''a Lazarus taxon." More importantly, by the end of your study, you will have some tools you can use in your daily life to help protect the great diversity of Earth's life.

Chapter Objectives

- Compare humans to other species in terms of resource needs and use, and ecosystem service benefits and effects.
- Define the concept of biodiversity.
- Quantify Earth's species diversity, according to scientists' current understanding.

- Describe patterns of biodiversity in space.
- Trace changes in biodiversity throughout Earth's history.
- Examine the evidence for the Sixth Extinction.
- Compare the Sixth Extinction to major extinctions before humans.
- Discuss the direct economic benefits of biodiversity.
- Evaluate ecosystem services provided by biodiversity.
- List the intangible (cultural, spiritual, religious) benefits of biodiversity.
- Relate biodiversity to social and political stability.
- Consider that biodiversity has intrinsic value apart from benefits to humans.
- Assess the potential for early human activities to contribute to Ice Age extinctions of large animals.
- Identify habitat loss as the primary cause of the Sixth Extinction.
- Relate the introduction of exotic species to loss of biodiversity.
- Explain the extent to which over exploitation has affected all levels of biodiversity.
- Connect energy use to extinction.
- Describe the effects of population growth and unequal distribution of resources on biodiversity.
- Recognize that pollution of water, land, and air contributes to the loss of species.
- Acknowledge that your daily activities and decisions can significantly help to protect biodiversity.
- Evaluate your consumption – of food, clothing, furniture, and cleaning products.
- Appreciate the importance of water resources and know how to use them wisely.
- Evaluate your choice and use of energy sources.
- Assess the importance of minimizing waste, and of using best practices for waste disposal.
- Know how to avoid transporting and releasing exotic species.
- Realize that you can practice sustainable management of your own land, from small yards to local, state, and federal lands which also belong to you.
- Describe sustainability and its role in decision-making.
- Explain how learning and active citizenship can contribute to protecting biodiversity.

10.2 What is Biodiversity?

"***The first rule of intelligent tinkering is to save all the pieces.***" –attributed to Aldo Leopold, but probably a shortened version of: ***"To save every cog and wheel is the first precaution of intelligent tinkering." - Aldo Leopold, Round River: from the Journals of Aldo Leopold*, 1953**

What are the "cogs" and "wheels" of life?

Although the concept of **biodiversity** did not become a vital component of biology and political science until nearly 40 years after Aldo Leopold's death in 1948, Leopold – often considered the father of modern ecology - would have likely found the term an appropriate description of his "cogs and wheels." Literally, biodiversity is the many different kinds (*diversity*) of life (*bio-*). Biologists, however, always alert to levels of organization, have identified three measures of life's variation. **Species diversity** best fits the literal translation: the number of different species (see the chapter on Evolution of Populations) in a particular ecosystem or on Earth (**Figure** 10.1). A second measure recognizes variation *within* a species: differences among individuals or populations make up **genetic diversity**. Finally, as Leopold clearly understood, the "cogs and wheels" include not only life but also the land (and sea and air) which supports life. **Ecosystem diversity** describes the many types of functional units formed by living communities interacting with their environments.

Although all three levels of diversity are important, the term biodiversity usually refers to species diversity. How many species do you think exist on Earth? What groups of species do you think are most abundant? Consider your own experience, and your study of biology up to this point. Think carefully, and write down your answer or exchange ideas with a classmate before you read further.

Figure 10.1: The most accessible definition of biodiversity is species diversity. How many species exist on Earth?

What is the Species Diversity of Earth?

There are three good answers to this question. As a member of one of Earth's most intriguing species, you should know them all!

1) Scientists have identified about 1.8 million species. (**Figure** 10.2)

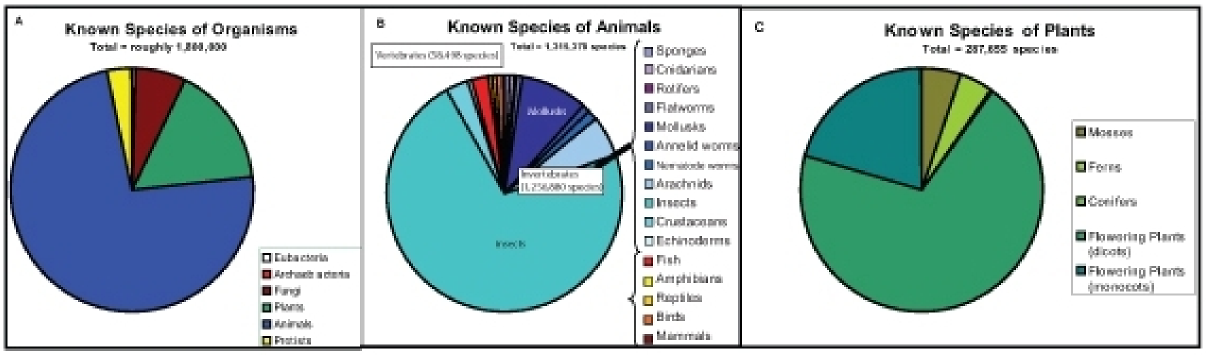


Figure 10.2: Among 1.8 million identified species (A), 1,315,378 are Animals (B), 287,655 are Plants (C), and only 259 are Archaebacteria. The Animal Kingdom is dominated by the Class Insecta, and the Plant Kingdom is dominated by flowering plants.

The relative numbers of species in each of the six kingdoms of life is shown in **Figure A** 10.2. The Animal Kingdom (dominated by the Insects, as shown in **Figure B** 10.2) includes the great majority of known species, and Archaebacteria, by far the fewest. Most scientists agree that Eubacteria and Archaebacteria are seriously underrepresented, due to their small size and chemistry-based diversity. This leads to a second, and perhaps better answer to our question:

2) No One Knows How Many Species Currently Live on Earth!

Does this lack of knowledge surprise you? Scientists are still discovering new species - not only microorganisms but also plants, animals, and fungi. At least 5 new species of marsupials, 25 primates, 3 rabbits, 22 rodents, 30 bats, 4 whales or dolphins, a leopard, and a sloth were identified between 2000 and 2007 – and these include only mammals! The vast majority of Eubacteria, Archaebacteria, Protist, and even Insect species may be yet unknown because their small size, remote habitats, and the chemical distinctions between species make them so difficult to detect. These challenges, however, have not prevented scientists from estimating Earth's biodiversity – bringing us to the third answer to our question:

3) Scientists Estimate that Between 5 and 30 Million Species Inhabit the Earth.

Estimates vary widely – from 2 million to 117.7 million, underlining our lack of knowledge. Most estimates fall between 5 and 30 million. Much remains to be learned about the diversity of microorganisms. For example, scientists have recently discovered that Archaebacteria – originally considered limited to extreme environments - may constitute as much as 40% of the ocean's microbial biomass. Few species have been identified. Estimates of global diversity of the better-studied Eubacteria vary from millions to billions, with orders of magnitude of error. As for multicellular organisms, the most "species-dense" terrestrial ecosystems, such as coral reefs and tropical rain forests, harbor most of the undiscovered species (**Figure** 10.3). Ironically, these ecosystems are also disappearing quickly. In summary, our estimates of biodiversity remain crude. However, the following conclusion is clear: given the current rapid loss of species, we will never know many of the species we are losing.

4) **The importance of some species still is not known.**

If they are important to the stability of an ecosystem and go extinct, this could have long-reaching affects on humans.

As a review from *The Principles of Ecology Chapter*, remember that according to Barry Commoner, there are Four Laws of Ecology (as follows). Explain how his laws govern the way nature does – and humans should – use energy and material resources in order to protect biodiversity.

- Everything is connected to everything else.
- Everything must go somewhere.
- Nature knows best.
- There is no such thing as a free lunch.

When we affect the ecosystem and biodiversity health in one region or biome, it is ultimately connected to others through geochemical and matter cycles.

Figure 10.3: Coral reefs (above) and tropical rain forests (below) have the greatest biodiversity of the many ecosystems on earth. They are also among the most threatened habitats. Because our knowledge of their species is incomplete, we are clearly losing species we do not (and never will) know.

Biodiversity Patterns in Space

Are Earth's 1.8 million known species evenly distributed across its surface? You may already be aware that the answer is a resounding "No!" We will compare two regions with relatively high diversity to begin our analysis.

Minnesota has relatively high ecosystem diversity, because three of the Earth's six major terrestrial biomes converge in this state (Prairie, Deciduous Forest, and Coniferous Forest). By contrast, Costa Rica comprises almost entirely of Tropical Rain Forest, and has only one quarter of the land area of Minnesota (**Figure** 10.4).

You might expect, then, that Minnesota would have a higher species diversity. Several groups of organisms are compared in the **Figure** 10.5. Note that a column is included for you to research your own state or region!

Clearly, biodiversity is much higher in Costa Rica than in Minnesota. Collecting leaves for your biology class in Costa Rica, you would need to study 2,500 different trees in order to identify the species! And

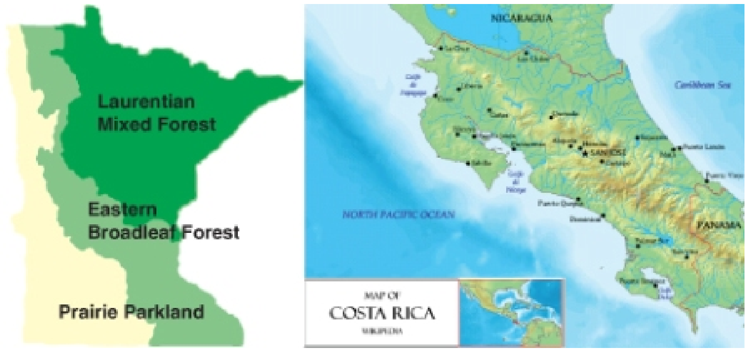


Figure 10.4: The state of Minnesota (

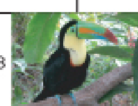
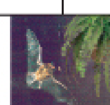
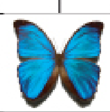
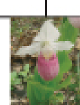
Group of Organisms	Number of Species: Minnesota	Number of Species: Costa Rica	Number of Species: Your State
Amphibians	18	150 	
Reptiles	27 	210	
Birds	400 (but 96 of these migrate, spending winter in the Rainforest)	848 	
Hummingbirds	1 	852	
Mamma ls	80	200 	
Bats	7 	100	
Butterflies	140	1000 	
Orchids	42 	1200	
Trees	43	2500 	

Figure 10.5: A comparison of species diversity within categories supports the increase in diversity from the poles to the equators. Costa Rica

you'd need to look carefully to distinguish tree leaves from those of the many **epiphytes** (plants which grow on top of others), vines, and strangler figs which climb the trunks and branches, "cheating" their way to the sunlight at the top of the canopy. In Minnesota, keys to native trees include just 42 species of conifers and deciduous broadleaved species. There, vines are relatively rare, and epiphytes are limited to colorful lichens.

The differences in biodiversity between Minnesota and Costa Rica are part of a general worldwide pattern: biodiversity is richest at the equators, but decreases toward the poles. Temperature is undoubtedly a major factor, with warmer, equatorial regions allowing year-round growth in contrast to seasonal limitations nearer the poles.

Generally, the more species, the more niches – so diversity begets diversity.

Does your country, state or region fit the general pattern of decreasing biodiversity from equator to poles?

Biodiversity Patterns in Time

How has Earth's biodiversity changed across time? The fossil record is our window into this pattern, although the window has limitations. Microorganisms are poorly preserved and distinguished only with difficulty; gene sequence studies of living bacteria have begun to fill in some missing data. For all organisms, recent rock layers are more accessible and better preserved than ancient ones.

Despite these drawbacks, fossils and gene studies show a distinct pattern of increasing biodiversity through time. As discussed in the chapter on the *History of Life,* the origin of life is not clearly understood; evidence suggests that life did not appear on Earth until perhaps 4 billion years ago. For several billion years, unicellular organisms were the only form of life. During that time, biodiversity clearly increased, as Eubacteria and Archaebacteria emerged from a common ancestor some 3 billion years ago, and Eukaryotes emerged by endosymbiosis about 2 billion years ago. However, we have not accurately measured the diversity of even today's microorganisms, so we have little understanding of changes in the diversity of microorganisms beyond these major events.

The emergence of multicellular life about 1 billion years ago certainly increased biodiversity, although we have little way of knowing whether it might have negatively affected the diversity of microorganisms. Fossils remain relatively rare until the famed Cambrian explosion 542 million years ago. Since then, a much more detailed fossil record (**Figure** 10.6) shows a pattern of increasing biodiversity marked by major extinctions.

The dramatic increase indicated for the last 200 million years is somewhat disputed. Some scientists believe it is a real increase in diversity due to expanding numbers of niches – diversity begets diversity, again. Others believe it is a product of sampling bias, due to better preservation of more recent fossils and rock layers. Most scientists accept the general pattern of increasing diversity through time, interpreting the magnificent biodiversity of life on Earth today as the result of billions of years of evolution.

Most scientists also accept at least the five major mass extinctions shown in **Figure** 10.6, and some hold that regular cycles govern extinction. Causes for these extinctions (more completely discussed in the *History of Life* chapter) remain incompletely understood; hypotheses include global climate change, major volcanic and continental drift events, dramatic oceanic change, and/or extraterrestrial impact or supernova events.

Increasingly accepted is a current Sixth or Holocene Extinction event. According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event - perhaps one of the fastest ever. We will explore the Sixth, or Holocene, Extinction in the next section of this lesson.

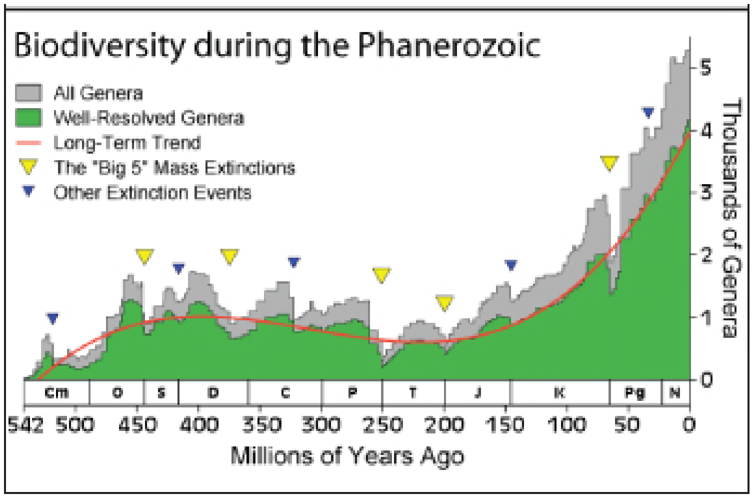


Figure 10.6: The fossil record for marine species over the past 542 million years shows a gradual increase in biodiversity interrupted by five major extinctions. Some scientists view the recent rapid rise in diversity as a result of better preservation of more recent rock layers and fossils.

The Current Loss of Biodiversity

"***For one species to mourn the death of another is a new thing under the sun.***" **-Aldo Leopold** *A Sand County Almanac,* 1949

Over 99% of all species that have ever lived on Earth are extinct. During the 5 major extinctions recorded in the Phanerozoic fossil record (**Figure** 10.6), more than 50% of animals disappeared. Evidently, extinction is natural. However, current extinctions may differ significantly in rate and cause. The IUCN (International Union of Concerned Scientists) has documented 758 extinctions since 1500 CE; for example, 6 species of giant, flightless *Moa* (**Figure A** 10.7) disappeared from New Zealand shortly after the arrival of Polynesians. Estimates of extinctions for the last century range from 20,000 to 2,000,000 species; as for diversity, we simply do not know the true figure.

Many scientists begin the Sixth Extinction with the Ice Age loss of large mammals and birds - part of a continuum of extinctions between 13,000 years ago and now. During that time, 33 of 45 genera of large mammals became extinct in North America, 46 of 58 in South America, and 15 of 16 in Australia. Climate change and/or human "overkill" are hypothetical causes. Supporting the significance of the "sudden" arrival of humans are the low numbers in Europe and South Africa, where humans had coevolved with large animals. The woolly mammoth (**Figure B** 10.7) is one of the many examples of large mammal extinctions from this period.

The first species to become extinct during recorded human history was the Dodo (**Figure C** 10.7), a flightless bird which had evolved without predators on an island in the Indian Ocean. Described in 1581, the fearless Dodo experienced hunting, forest habitat destruction, and introduced predators, and became extinct before 1700 – a story repeated for many more species over the following three centuries. Unfortunately, the story extends back in time, as well; over the past 1100 years, human activity has led to the extinction of as many as 20% of all bird species... a tragic loss of biodiversity.

Harvard Biologist E.O. Wilson estimated in 1993 that the planet was losing 30,000 species per year - around three species per hour. In 2002, he predicted that if current rates continue, 50% of today's plant and animal species will be extinct within the current century – compared to hundreds of thousands or even millions of years for pre-human mass extinctions. A dramatic global decline in amphibian populations in less than 30 years headlines the recent rise in extinction. Herpetologists report that as many as 170 species

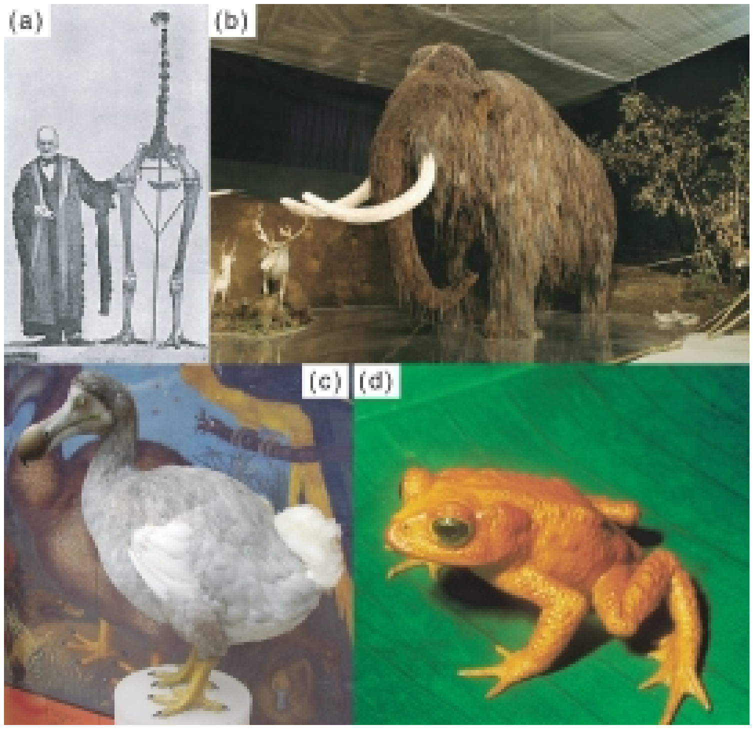


Figure 10.7: A gallery of species which have succumbed to the Sixth Extinction: A: one of six species of

have become extinct within that time, and at least one-third of remaining species are threatened. Costa Rica's Golden Toad (**Figure D** 10.7), first described in 1966, was last seen in 1989 and has become a poster species for amphibian declines.

10.3 Why is Biodiversity Important? What are We Losing?

Why should humans care if biodiversity declines? Does it matter that we have 170 fewer amphibians, or that we are losing thousands of species each year, when the Earth holds millions of other species, and life has been through extinction before? The answer is a definitive yes! It matters to us even if we consider only the economic and spiritual benefits to humans. It matters to us because we do not even understand the myraid of indirect benefits – now recognized as **ecosystem services**- that we reap from other species. And, of course, it matters to other species as well.

Direct Economic Benefits of Biodiversity

- ***Food Supply***: **Monocultures** (large-scale cultivation of single varieties of single species) are extremely vulnerable to disease. A water mold caused the infamous Irish potato famine where potatoes had been bred from a single Incan variety. As recently as 1970, blight swept the corn belt where 80% of maize grown in the U.S. was a single type. According to the Food and Agricultural Organization of the United Nations, humans currently cultivate only 150 plant species, and just four provide over half of the food we eat. Just 15 animal species make up over 90% of our livestock.

Potential for hybridization requires a diverse "bank" of wild, native species. Contemporary breeders increase genetic diversity by hybridizing crop species with wild species adapted to local climate and disease (**Figure** 10.8).

Figure 10.8: Wild varieties of domesticated crops, such as this unusually shaped Latin American maize, hold the potential to enhance productivity, nutritional value, adaptation to local climates, and resistance to local diseases through hybridization. Loss of biodiversity limits our ability to increase the genetic diversity of crops.

- ***Clothing, Shelter, and Other Products***: As many as 40,000 species of plants, animals, and fungi provide us with many varied types of clothing, shelter and other products. These include timber, skins and furs, fibers, fragrances, papers, silks, dyes, poisons, adhesives, rubber, resins, rubber, and more.

- ***Energy***: In addition to these raw materials for industry, we use animals for energy and transportation, and biomass for heat and other fuels. Moreover, hydroelectric power depends on ecosystem structure: Chinese scientists calculated that the economic benefits of maintaining forest vegetation in the Yangtze River watershed "produced" more than twice the economic value of timber (had it been harvested) in annual power output.

- ***Medicine and Medical Models***: Since the first microorganisms competed for food, evolution has been producing chemicals for "warfare" and "defense" in bacteria, fungi, plants, and animals; **Figure** 10.9 shows several used by humans. According the American Museum of Natural History Center for Biodiversity Conservation (AMNH-CBC), 57% of the most important prescription drugs come from nature, yet only a fraction of species with medicinal potential have been studied.

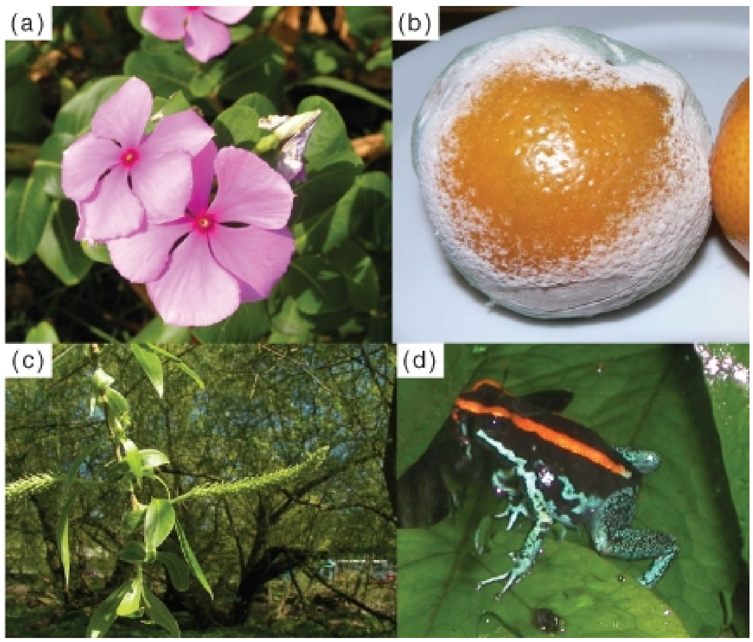


Figure 10.9: A pharmacopoeia of the living world: The Rosy Periwinkle (A) is the source of two chemotherapy drugs effective against leukemias. The mold

Unique features of certain species have opened windows into how life works. For example, the Atlantic squid's giant axon revealed the basics of neurophysiology, and the horseshoe crab's (**Figure D** 10.11) optic nerve and photoreceptors taught us how vision works. Other animals serve as disease models; as far as we know, other than humans, only armadillos suffer from leprosy, and only sea squirts form kidney stones.

- ***Efficient Designs: Inspiration for Technology***: **Biomimicry**, also known as biomimetics or **bionics**, uses organisms for engineering inspiration and human innovation. Rattlesnake heat-sensing pits, for example, suggested infrared sensors. Zimbabwe's Eastgate Centre **Figure** 10.10 incorporates air-conditioning principles from termite mounds. The 2006 Mercedes-Benz *Bionic* employs the body shape of the yellow box fish to combine high internal volume and efficient aerodynamics. Biomimetics professor Julian Vincent estimates that only 10% of current technology employs the highly efficient biological designs crafted by evolution and natural selection. Loss of biodiversity can be viewed as the loss of millions of years of evolutionary wisdom.

Figure 10.10: Bionics, or biomimicry, engineers structures based on biological designs made efficient by millions of years of evolution and natural selection. Above: The air-conditioning efficiency of a termite mound (left) inspired the design of the Eastgate Centre in Zimbabwe (right), which requires just 10% of the energy needed for conventional building of the same size. Below: The rigid exoskeleton and low-drag body shape of the tropical yellow box-fish (left) inspired the 2006 Mercedes-Benz

- ***Warnings of Toxins and Other Ecosystem Disruptions***: If you know how miners use canaries to detect poisonous gases underground, you will understand how widespread extirpation of peregrine falcons (**Figure E** 10.11) warned us about the dangers of the pesticide DDT and food chain concentration of toxins.

Indirect Benefits of Biodiversity: Ecosystem Services

- ***Increasing Ecosystem Productivity***: Ecologist David Tilman compared grassland plots to show that increasing species diversity increased overall productivity (yield). Different plants utilize different resources, so a variety of plants may more completely use resources within an area. As noted above, diversity also reduces system vulnerability to pests and disease.

- ***Increasing Ecosystem Stability***: Tilman observed his grassland plots through several cycles of drought and documented a similar relationship between biodiversity and stability. Plots which were more diverse were more resistant to drought and later recovered more completely. Reducing ecosystem vulnerability to pests and disease may also be a factor in the relationship between diversity and stability. As you have learned before, diversity among individuals within a species increases the chance that at least some will survive environmental change; similarly, diversity among species within an ecosystem increases the chance that at least some species will survive environmental change.

- ***Maintaining the Atmosphere***: As you learned in the chapters on photosynthesis and respiration, plants and algae produce the O_2 which makes up 20% of the atmosphere essential to aerobic organisms, and remove CO_2 produced by respiration and burning fossil fuels. As Joseph Priestley expressed this service, plants "restore the air" which has been "injured by the burning of candles" or "infested with animal respiration." O_2 is also critical to life because it helps to maintain the ozone shield, protecting life from dangerous Ultra-Violet radiation.

- ***Maintaining Soils***: Soil microorganisms maintain nutrients in complex but critical chemical pathways. Vegetation and litter prevent erosion of soils which require thousands of years to form. Estimates suggest that erosion destroys as many as 3 million hectares of cropland annually, and that as much as one-fifth of the world's cropland is "desertified" through salination, acidification, or compacting.

- ***Maintaining Water Quality***: Water treatment plants rely in large part on microorganisms for water purification, and natural systems do the same. In nature, wetland, waterway, and watershed root systems combine with soil adsorption and filtration to accomplish water purification. When New York City decided to restore the Catskill watershed, their $1-1.5 billion investment in "natural capital" contrasted favorably with the $6-8 billion initial cost and $300 million annual operating cost of a new treatment plant.

- "***Fixing***" ***Nitrogen***: One of the most amazing aspects of biological systems on earth is their absolute need for nitrogen – to build the proteins and nucleic acids upon which life depends – and their nearly universal dependence on microorganisms to "fix" atmospheric N_2 gas and recycle the nitrogen of waste and death. Only after the bacterial "service" of processing nitrogen is it available in usable chemical form to plants, and through them, to animals (**Figure A** 10.11).

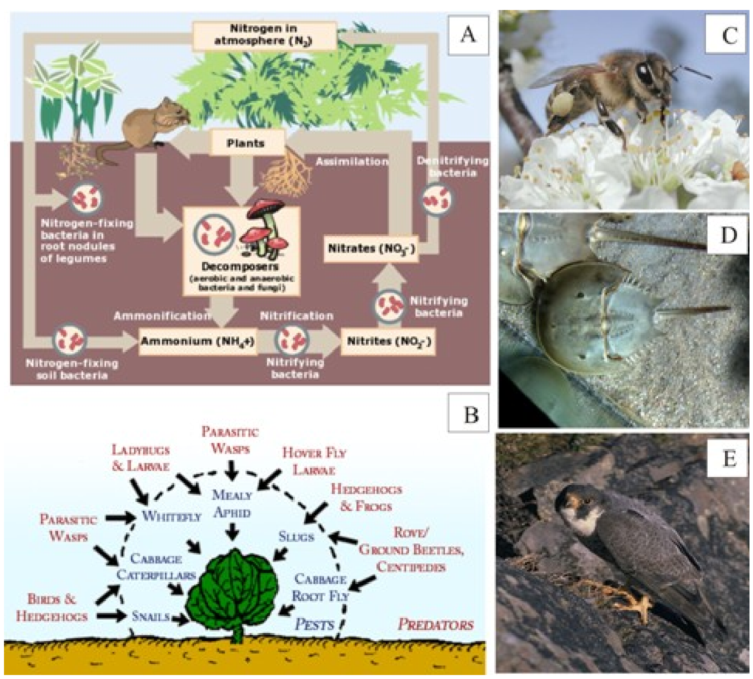


Figure 10.11: Ecosystem services which depend on biodiversity include nitrogen fixation (A), pest control (B), pollination (C), medical models such as the horseshoe crab optic nerve and photoreceptors (D), and early warning about toxins, e.g. the peregrine falcon

- ***Nutrient Recycling and Waste Disposal***: Bacteria and nitrogen are not the only contributors to the waste management services of ecosystems. Fungi, protists, and scavengers help to decompose waste and dead organisms so that new life can reuse the available nutrients.

- ***Pollination***: The list of biotic pollinators, essential for sexual reproduction in many plants, is long including not only insects such as wasps, bees, ants, beetles, moths, butterflies, and flies, but also fruit bats and birds such as hummingbirds, sunbirds, spiderhunters, and honeyeaters. Although U.S. crops have relied on commercial honeybees (which are "migrated" to keep pace with maturing crops!), native pollinators in nearby forests or wild grasslands have been shown to improve the productivity of apples or almonds by 20%. The American Institute of Biological Sciences estimates that native insect pollination is worth $3.1 billion annually. Current alarm over honeybee colony collapse highlights the importance of biodiversity to the ecosystem service of pollination.

- ***Pest and Disease Control***: According to the AMNH-CBC, farmers spend $25 billion annually on pesticides, while predators in natural ecosystems (**Figure B** 10.11) contribute 5 to 10 times that value in pest control. Costs associated with the use of chemical pesticides (such as water pollution) add to the value of natural pest control. Natural enemies are adapted to local environments and local pests, and do not threaten each other's survival (or ours!) as do broad-spectrum chemical pesticides. Preservation of natural enemies is associated with preservation of plant diversity, as well. Disrupted ecosystems can lead to increasing problems with disease. In Africa, deforestation has led to erosion and flooding, with consequent increases in mosquitoes and malaria.

Aesthetic Benefits of Biodiversity

- ***Cultural, Intellectual, and Spiritual Inspiration***: Music, art, poetry, dance, mythology, and cuisine all reflect and depend on the living species with whom we share the Earth. Our cultures reflect local and regional variations, and as such, biodiversity underlies our very identities. The beauty and tranquility of living ecosystems have inspired environmentalists (Rachel Carson, Aldo Leopold), spiritualists (Thomas Berry), and writers such as (Barry Lopez) throughout history. Recently, the increasing distance of human society from the natural world has raised concerns about our psychological and emotional health; E.O. Wilson has proposed that *biophilia* (love of the living world) is an increasingly ignored part of our human psyche, and Richard Louv believes that too many of our children suffer from "nature deficit disorder" caused by our increasing alienation from nature.

- ***Recreational Experiences***: Many people choose to use vacation and recreation time to explore natural ecosystems. Outdoor recreational activities – many of which are increasing in popularity - include hunting, fishing, hiking, camping, bird-, butterfly- and whale- watching, gardening, diving, and photography. Indoor hobbies such as aquariums also celebrate biodiversity. For Costa Rica, Ecuador, Nepal, Kenya, Madagascar, and Antarctica, ecotourism makes up a significant percentage of the gross national product. Ideally, ecotourism involves minimal environmental impact, conservation of bio- and cultural diversity, and employment of indigenous peoples.

Political and Social Benefits of Biodiversity

Some analysts relate biodiversity to political and social stability. Unequal access to food, clothing, water, and shelter provided by diverse ecosystems threatens social equity and stability. Land ownership and land use practices which threaten biodiversity often marginalize poorer people, forcing them into more ecologically sensitive areas and occupations. Poverty, famine, displacement, and migrations are problems related to loss of biodiversity which have already led to billions of dollars in relief costs and significant local armed conflict.

Intrinsic Value of Biodiversity

Many people value biodiversity for its inherent worth, believing that the existence of such a variety of genes, species, and ecosystems is reason enough for our respect. Intrinsic value goes beyond economic, aesthetic, environmental, and political benefits. For many people, intrinsic value alone imposes great responsibility on us to monitor our actions in order to avoid destroying the diversity of life.

Why is biodiversity important? It supplies us with essential resources, raw materials, and designs which have direct economic value. It enhances the stability and productivity of ecosystems which in turn provide essential, under-appreciated services. These services, too, have great economic value, although we are only beginning to recognize their importance as we experience their loss. Biodiversity is critical for cultural identity, spiritual and intellectual inspiration, and our own re-creation. Biodiversity goes hand-in-hand with social and political stability. And for many people, biodiversity has inherent worth apart from its many benefits for us and our environment.

Biodiversity is critically important for us and for the Earth, and it is declining at an unprecedented rate. What is causing current extinctions? What can we – what can YOU – do to help?

10.4 Causes of the Sixth Extinction: Human Actions and the Environment

What are the causes of the Sixth Extinction? Many point to the Anthropocene, the new geological era brought about by Humans (see the Anthropocene chapter). There is nearly universal agreement that most result from human activities (**Table** 10.1 and **Figure** 10.12). Although our activities have changed, we remain the single species most able to alter the Earth's genetic, species, and ecosystem biodiversity.

Table 10.1:

Continent/Island	Human Settlement (Years Before Present)	Extinctions Which Followed
Africa, Eurasia	Humans evolve here	relatively few extinctions
Indonesia	50,000	50% of large mammal species
Australia	40,000	55 species large mammals, reptiles, and birds
North and South America	10,000 - 12,500	70-80% of large mammals (at least 135 species) within 1000 years
Mediterranean Islands	10,000	large mammals and reptiles
West Indies	7,000	Mammals, birds, reptiles all 5 endemic mammals of Puerto Rico
Madagascar	2,000	virtually all large endemic land mammals, reptiles, and birds within 1500 years
Hawaiian Islands	1,500 (Polynesians) 250 (Europeans)	2/3 of native vertebrate species, 90% of bird species after European arrival, 20 more bird species
New Zealand	1,300	No mammals originally Frogs, lizards, and over 1/3 (40 species) of birds

Convincing evidence for human responsibility for Ice Age extinctions is outlined in **Figure** 10.12. Comparing Ice Age to pre-human extinctions provides more evidence:

- Ice Age extinctions affected large animals disproportionately; pre-human extinctions affected all body sizes.
- Ice Age extinctions occurred at different times in different regions; pre-human extinctions were global and simultaneous.
- Recent extinctions follow human migration with regularity.
- The "syncopated" pattern does not fit climate change, and earlier interglacial periods did not see similar extinctions.

Although the data above has led to considerable agreement about human responsibility for the early

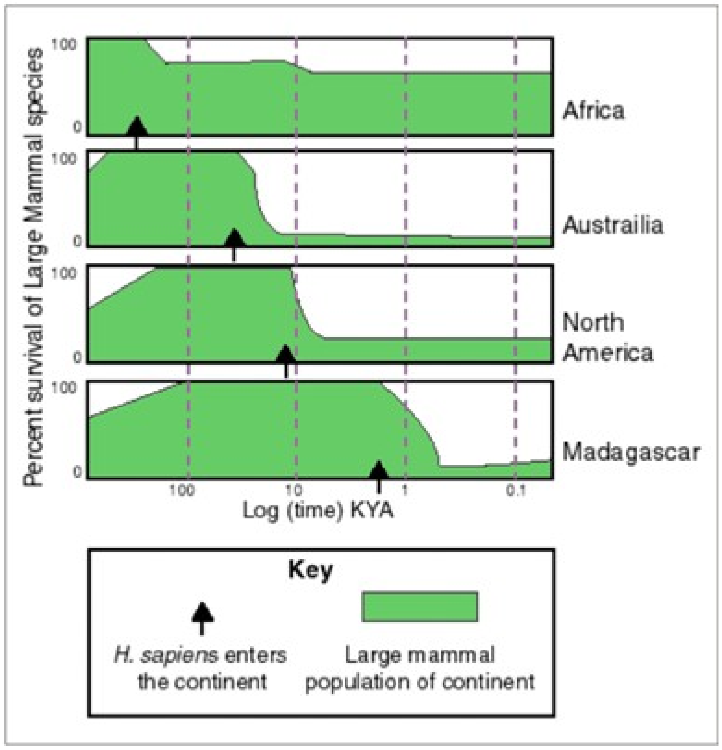


Figure 10.12: Large animal extinctions followed the arrival of humans in many regions of the world, suggesting that human activities caused the extinctions.

Holocene extinctions, scientists still debate exactly how human activities caused extinctions. Hypotheses include:

1. **Overkill**: Animals outside Africa and Eurasia evolved in the absence of humans. Many did not fear humans and would have been easily killed, explaining the disproportionate numbers of large species affected.
2. **Cascade effects**: Extinctions of very large animals could have had major effects on ecosystems, including secondary extinctions. Loss of predators could have led to overpopulation and starvation of prey species. Loss of large herbivores would have affected their predators. Removal of even a single **keystone species** could have destabilized complex ecosystem interactions, leading to multiple extinctions.
3. **Disease**: Humans often brought along rats, birds, and other animals as they migrated to new regions. Animals in those new regions, however, would not have evolved resistance to the diseases they carried. Avian malaria, for example, is still spreading through Hawaii, having already caused the extinctions of many bird species.
4. **Predation by exotic animals**: The rats, birds, and other animals accompanying humans brought not only disease but also new appetites to regions where animals had evolved without predators. Like humans, these animals found the “naïve” prey easy to capture.
5. **Habitat destruction**: Deforestation and agriculture accompanied humans, and the loss of habitat inevitably resulted in loss of species.

These effects of early human habitation foreshadow today’s even greater threats to biodiversity. Overpopulation, industrialization, technology, cultural differences, and socioeconomic disparities compound the six major causes of today’s Biodiversity Crisis. Most experts agree on the primary cause of extinction today:

Causes of Extinction #1: Habitat Loss

Habitat loss, degradation and fragmentation is universally accepted as the primary threat to biodiversity. Agriculture, forestry, mining, and urbanization have disturbed over half of Earth's vegetated land. Inevitably, species disappear and biodiversity declines.

Conversion for **agriculture** is a major reason for habitat loss. Within the past 100 years, the area of land cultivated worldwide has increased 74%; grazing land increased 113%. Agriculture has cost the United States 50% of its wetlands and 99% of its tallgrass prairies. Native prairie ecosystems (**Figure** 10.13) - which comprise of thick, fertile soils, deep-rooted grasses, a colorful diversity of flowers, burrowing prairie dogs, owls and badgers, herds of bison and pronghorns, and booming prairie chickens, - are virtually extinct.

Figure 10.13: Habitat loss is the #1 cause of extinction today. In the U.S., over 99% of tallgrass prairies have been eliminated in favor of agriculture. Big bluestem grasses as tall as a human (center) and (clockwise from top) prairie chickens, prairie dogs, burrowing owls, yellow and purple coneflowers, blue grama grass, and bison make up part of the prairie community.

The largest cause of deforestation today is **slash-and-burn agriculture** (**Figure** 10.14), used by over 200 million people in tropical forests throughout the world. Depletion of the surprisingly thin and nutrient-poor soil often results in abandonment within a few years, and subsequent erosion can lead to desertification. Half of Earth's mature tropical forests are gone; one-fifth of tropical rain forests disappeared between 1960 and 1990. At current rates of deforestation, all tropical forests will be gone by 2090.

Poverty, inequitable land distribution, and overpopulation combine in third world countries to add pressure to already stressed habitats. Use of firewood, charcoal, crop waste, and manure for cooking and other energy needs further degrade environments, threatening biodiversity through habitat loss.

Figure 10.14: Slash-and-burn agriculture is practiced by over 200 million people throughout the world; this photo was taken in Panama. Because of thin, nutrient-poor soils, plots are abandoned within just a few years. Experts predict that if current rates continue, all tropical forests will be gone by 2090.

Causes of Extinction #2: Exotic (Alien or Invasive) Species

Technology has made the human species the most mobile species of any which has ever lived. Both intentionally and inadvertently, humans have extended their mobility to a great number of other species, as well. Ships from Polynesian times (as long ago as 3500 BP) to the present have transported crop species and domesticated animals as well as stowaway rats and snakes. Recently, cargo ships have transported Zebra Mussels, Spiny Waterfleas, and Ruffe deep into the Great Lakes via ballast water. Europeans brought Purple Loosestrife and European Buckthorn to North America to beautify their gardens. Shakespeare enthusiast Eugene Schieffelin imported the now-ubiquitous European Starling to Central Park in the 1890s because he thought Americans should experience every bird mentioned in the works of Shakespeare. Australians imported the Cane Toad in an attempt to control the Cane Beetle, a native pest of sugar cane fields. The Brown Tree Snake (**Figure** 10.15) may have hitchhiked in the wheel-wells of military aircraft to Guam - and subsequently extirpated most of the island's "naïve" vertebrate species.

Figure 10.15: Many scientists consider exotic species to be the #2 cause of loss of biodiversity. One of the most infamous, the Brown Tree Snake (left), hitch-hiked on aircraft to Pacific Islands and caused the extinctions of many bird and mammal species which had evolved in the absence of predators. The Nile Perch (right) was intentionally introduced to Lake Victoria to compensate for overfishing of native species. The Perch itself overfished smaller species, resulting in the extinction of perhaps 200 species of cichlids.

Many of these **exotic** (non-native) **species**, away from the predation or competition of their native habitats, have unexpected and negative effects in new ecosystems. Freed from natural controls, introduced species can disrupt food chains, carry disease, out-compete natives for limited resources, or prey on native species directly - and lead to extinctions. Some hybridize with native species carefully tuned to local climate, predation, competition, and disease, resulting in **genetic pollution** which weakens natural adaptations. Others change the very nature of the habitats they invade; Zebra Mussels, for example, colonize most manmade and natural surfaces (including native mussels), filter-feeding so intensely that they increase water clarity and enrich bottom habitats with their waste.

Globalization and tourism are increasing the number of exotics which threaten biodiversity throughout the world, breaking down geographic barriers and threatening the wisdom of millions of years of evolution and natural selection. If current trends continue, our increasingly interconnected world will eventually be dominated by just a few fast-growing, highly adaptable, keenly competitive ‘‘super-species” rather than the rich diversity we have today. Some biologists, noting that invasive exotics closely resemble what we consider to be ‘‘weed” species, have concluded that the world’s #1 weed species is – did you guess it? – none other than *Homo sapiens.*

Causes of Extinction #3: Overexploitation

The modern equivalent to overkill, **overexploitation** threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species. Practices such as clear-cutting old growth forests, strip mining, and driftnet fishing go beyond harvesting of single species or resources to degrade entire ecosystems. Technology-aided over-harvesting has reduced one of the richest fisheries in the world - the Grand Banks off the coast of Newfoundland – to an estimated 1% of what they were in 1977 (**Figure** 10.16). In 2003 in the journal *Nature,* Canadian biologists published an analysis of data showing that ‘‘industrialized” fishing has reduced large predatory fish worldwide by 90%. Some species’ stocks are so depleted that less desirable species are illegally sold under the names of more expensive ones; in 2004, University of North Carolina graduate students tested DNA from fish sold as ‘‘red snapper” from eight states and found that different species made up 77% of the fish tested! Overexploitation happens on the level of genes and ecosystems as well as individual species. Forest plantations, fish hatcheries and farms, and intensive agriculture reduce both species diversity and genetic diversity within species.

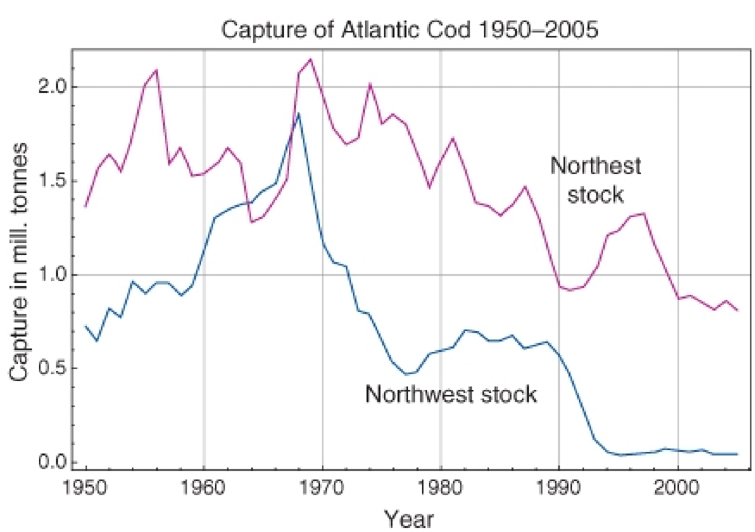


Figure 10.16: Overexploitation of Atlantic cod threatens one of the world

Causes of Extinction #4: Global Climate Change

Our increasing reliance on fossil fuels is altering the Earth's atmosphere and climate. The effects include acid rain, breaks in the ozone layer shielding us from ultraviolet radiation, and greenhouse gases which raise the Earth's air and ocean temperatures and sea levels. Burning tropical rain forests compounds the effect, releasing carbon as CO_2 and eliminating the forest's ability to **sequester** carbon – remove carbon as CO_2 from the atmosphere - via photosynthesis. Inevitably, changing air and water temperatures, rainfall patterns, and salinity threaten species adapted to pre-warming conditions, and biodiversity declines globally. This concern is the topic of the Climate Change Lesson .

Causes of Extinction #5: Overpopulation

In 1960, Earth's human population stood at 3 billion. By 1999, we had grown to 6 billion. This unprecedented growth, together with developments in technology, has added immense pressure to resource and land use. Overpopulation compounds all of the aforementioned threats to biodiversity, and unequal distribution of resources extends the consequences to social and political instability. Human population growth continues (see the chapter on Biology of Populations). Growth rates vary – ominously, from a biodiversity perspective: the highest rates are in third world tropical countries where diversity is also highest. We have already seen how slash-and-burn agriculture and Lake Victoria fisheries connect socioeconomic changes to loss of biodiversity.

Causes of Extinction #6: Pollution

Pollution adds chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life. To a certain extent, pollution has not kept pace with population growth, at least in Europe and the US. Startling events such as the oil-and-debris-covered and lifeless Cuyahoga River catching fire in 1969 finally provoked the U.S. to stop viewing air and waterways as convenient dumping grounds for waste. Environmental legislation, including the establishment of the Environmental Protection Agency (EPA) has improved both water and air quality. Heeding the warning provided by the extirpation of the Peregrine Falcon from the Eastern U.S., scientists discovered that many synthetic chemicals concentrate as they move through the food chain (**biological magnification**), so that toxic effects are multiplied. DDT – the cause of the Peregrine's decline – was banned in the U.S., and regulation of pesticides was transferred from the Department of Agriculture to the EPA.

And yet, pollution continues to contribute to habitat degradation worldwide, especially in developing countries.

- **Air Pollution**: Knows no boundaries and growing concern about its effects on climate earn this topic two lessons later in this chapter. Acid rain, ozone depletion, and global warming each affect diversity.
- **Water Pollution**: Especially from threatens vital freshwater and marine resources in the US and throughout the world. Industrial and agricultural chemicals, waste, acid rain, and global warming threaten waters which are essential for all ecosystems. Threats to water resources are discussed in Lesson 2.
- **Soil Contamination**: Toxic industrial and municipal wastes, salts from irrigation, and pesticides from agriculture all degrade soils - the foundations of terrestrial ecosystems and their biodiversity. These and other threats to soils are discussed in Lesson 2, Natural Resources.

Outside the developed world, pollution controls lag behind those of the U.S. and Europe, and developing nations such as China are rapidly increasing levels of pollution. Many pollution problems remain in industrialized countries, as well: industry and technology add nuclear waste disposal, oil spills, thermal pollution from wastewater, light pollution of the night skies, acid rain, and more to the challenges facing Earth's biodiversity. Many will be discussed in the following lesson on Natural Resources, and you can certainly research more about those which interest or concern you. Our next task will be to switch from the doomsday report of problems and causes to a discussion of what WE – ordinary citizens – can do to help protect Earth's biodiversity.

10.5 Protecting Biodiversity

Consider the following facts from the American Museum of Natural History's Center for Biodiversity and Conservation (AMNH-CBC) and the Environmental Protection Agency (EPA):

Every year, Americans:

- Throw away at least 2 billion disposable razors
- Discard enough paper and wood to heat 5 million homes for 200 years
- Drink more than two billion gallons of bottled water, costing 900 times more money than tap water – not counting the energy and toxics involved in packaging and shipping
- Retire up to 130 million cell phones, containing toxic metals such as arsenic, cadmium, and lead
- Generate about 3 million tons of toxic electronics waste (e-waste), and recycle only about 11%

Do any of these everyday experiences apply to you? You may be surprised to learn there is quite a lot you can do to help. Read carefully through the suggestions below, noting those that appeal to you strongly and those which seem most feasible. Many involve little more than awareness in decisions you already or will soon make.

Consume Thoughtfully and Wisely: Reduce Your Consumption Where Possible. Re-use, and Recycle. Make Durability and Efficiency Your Criteria for Product Purchases.

In general, when you buy:

- Buy locally whenever possible to reduce transportation costs for you and for the environment.
- Be aware of the natural resources used to make and transport any product you buy.
- Substitute other materials for plastics - which are made from petroleum and produce toxic waste.

- When you buy food plan your diet for your own health and that of the environment.
- Eat low on the food chain. Top carnivores get the least energy and the most poison.
- Buy local produce in season – to reduce transportation costs and the need for pesticides.
- Buy at farmers' markets or a Community Supported Agriculture (CSA) programs to support local farmers and reduce demand for energy-consuming and polluting large-scale agriculture and marketing.
- Choose organic produce - for your own health and to protect the environment from excessive nutrients and pesticides (**Figure** 10.17).

- ***When you buy fish for food or for your aquarium***
- Check to be sure that commercial species are not from overharvested areas,
- Verify that tropical saltwater fish were not collected using cyanide.

- ***When you need paper products,*** be sure they are made of recycled fiber.
- Or consider alternative materials such as hemp, kenaf, cornstarch, or old money or maps.
- Replace paper napkins and paper towels with cloth.
- Reuse envelopes and boxes. Wrap gifts in the comics or reusable cloth gift bags.

Figure 10.17: Eat with the environment and your health in mind! In the United States, the Department of Agriculture (USDA) sets standards for organic products and certification. The green-and-white seal identifies products which have at least 95% organic ingredients. The program is helpful to consumers, but not without controversy (read Barbara Kingsolver

- ***When you buy products for cleaning,painting,or washing your car,***check the ingredients to be sure you are not exposing yourself and the environment to unnecessary toxins. Vinegar and baking soda work wonders!

- ***When you buy wood or wood products*** be sure harvesting followed **sustainable forest management** – practices which ensure future productivity, biodiversity, and ecosystem health.
- Look for SmartWood, FSC (Forest Stewardship Council) or similar labels.
- Consider recycled or salvaged wood.

Figure 10.18: One drop per second from a dripping faucet wastes 2,700 gallons of water per year and adds to sewer and/or septic costs, as well.

When You Use Water, Remember Its Importance To All Life

- Check for water leaks and repair drips with new washers (**Figure** 10.18).
- Use low-flush toilets and low-flow faucets and shower heads.
- Have your tap water tested; use filters or refillable delivery if needed, rather than bottled water.

When You Must Use Energy, Consider Consequences and Choose Your Source Carefully

- Unplug electronic equipment such as fax machines, power tools, and anything connected to a remote control.
- Turn off power sources and lights when not in use.
- Use your bicycle, and support bike-friendly cities and roads.
- Walk! It's good for you, as well as the environment.
- Use public transportation, and support its expansion.
- Make energy-efficiency your #1 priority when you purchase appliances.
- Make fuel-efficiency your #1 priority if you purchase a car.
- Turn down your thermostat, especially at night. Just 2°F saves 500 pounds of greenhouse-inducing CO_2!
- Weatherstrip and caulk doors and windows.
- Replace incandescent with fluorescent light bulbs, which are four times as efficient and last far longer.
- The EPA Energy Star Logo helps consumers to identify energy-efficient products. The less fossil fuel energy we use, the fewer greenhouse gases we release, reducing the threat of climate change.

Figure 10.19: Computer equipment becomes obsolete quickly and contains toxins such as lead and mercury. Consider donating your obsolete equipment, and if you must discard it, be sure you follow specific guidelines for recycling and hazardous waste disposal.

When You Must Dispose of Waste, Learn the Best Practice for Its Disposal

- Reduce or eliminate your use of plastic bags, sandwich bags, and six-pack plastic rings (and don't release balloons!) so that endangered sea turtles do not mistake these for their favorite food - jellyfish.
- Minimize and compost food waste.
- Recycle motor oil and unused paint.

- Use appropriate local hazardous waste facilities for recommended chemicals and medicines.
- Donate obsolete computers and other electronic equipment – or if you cannot, recycle such “e-waste” properly (**Figure** 10.19).

Don’t Contribute to the Burgeoning Problem of Exotic Species

(The following points reference **Figure** 10.20.)

- Don’t release aquarium fish, turtles, birds, or other pets into the wild.

Figure 10.20: Exotic (invasive or alien) species are often considered the #2 cause of extinction. Learn how to avoid transporting them!

- Clean your boat thoroughly after use, and avoid traveling with wild plants and animals.
- Your pet is also considered to be an exotic species. Don’t let your pets hunt birds or wild animals.

Practice Sustainable Management on Your Own Land, Even If it is "Only" a Small Yard

- Minimize nonpoint source pollution by using organic or natural pesticides and fertilizers.
- Plant shade trees for air-conditioning and to absorb CO_2.
- Water plants and lawns in the evening.
- Better yet, use native and/or drought-tolerant plants for landscaping.
- Remember that City, County, State, and Federal lands are your lands, too. Get involved in local zoning and land use planning to ensure that development follows sustainable guidelines.

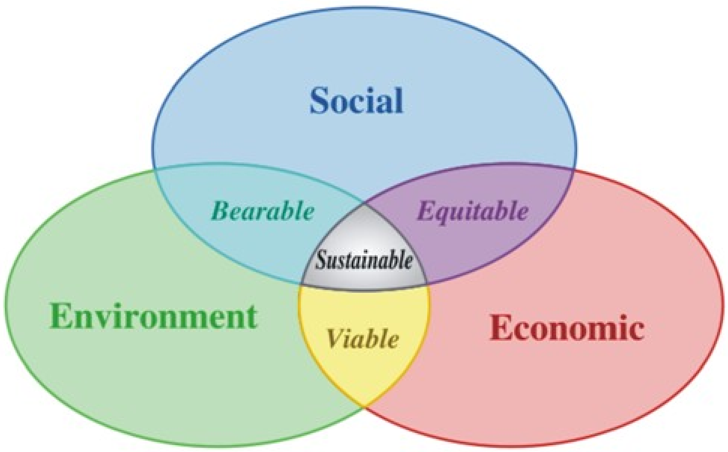


Figure 10.21: Sustainability as a goal in decision-making seeks the intersection of three sets of values. The environmental component includes maintaining ecosystem quality indefinitely.

Adopt and Spread Sustainable Perspectives and Philosophy

- Focus on diversity as a whole – genes, communities and ecosystems – rather than single "poster" species.
- Support the inclusion of ecosystems services in economic valuations.
- Encourage protection of areas large enough to accommodate migration, flooding, buffer zones, pollution from nearby development, and people and their activities.
- Realize that inequitable distribution of population, land, resources, education, and wealth threatens biodiversity.
- Promote the concept of sustainability as a guide for conservation decisions (**Figure** 10.21).
- Join philosophers and religious and community groups to explore environmental ethics.
- Help *everyone* understand basic ecology and the wealth of biodiversity shaped by billions of years of evolution.

Learn More!

- About the species with which you share the Earth.
- About local, national, and international threats to biodiversity

- About more solutions as they develop
- Jump in! Join local groups which monitor ecosystem health: Frog Watch, River Watch, or Bird Counts.
- Educate yourself about complex issues such as government subsidies and new technologies.
- Find out about local protected lands and volunteer your time and energy to restore native ecosystems.

Activate!

- Exercise your citizenship to protect biodiversity. Vote, communicate your views, and push for stronger environmental protection laws.
- Support organizations which promote national reserves, international treaties, and resource conservation.
- Support efforts by zoos, arboretums, museums and seed banks to help maintain genetic diversity through research, breeding, educational, and fundraising programs.

10.6 End of Chapter Review & Resources

Chapter Summary

Like all species, humans depend on land, water, air, and living resources for food, energy, clothing, and **ecosystem services** such as nutrient recycling, waste disposal, and renewal of soil, freshwater, and clean air. Unlike other species, human technology supplements ‘‘natural” energy resources with fossil fuels and exploits both biotic and abiotic resources and produces wastes beyond the biosphere’s capacity for renewal. Biodiversity encompasses all variation in living systems, including genetic, species, and ecosystem diversity. Scientists do not know how many species currently inhabit the Earth; the vast majority of Bacteria and Archaea, Protists and Insects, are probably unknown. We discover new species of animals, plants, and fungi each year. About 1.8 million species have been identified, and most estimates of Earth’s overall species biodiversity fall between 5 and 30 million. In general, biodiversity is highest near the equator, and decreases toward the poles. Biodiversity ‘‘hotspots” such as the California Floristic Province and unique habitats such as bogs occasionally disrupt the overall pattern. The fossil record and DNA analysis reveal a gradual increase in Earth’s biodiversity after the first prokaryotes appeared roughly 4 billion years ago. Within the past 600 million years, a more detailed fossil record shows increasing biodiversity interrupted by five major extinctions in which at least 50% of species disappeared. According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event. Many scientists regard the Ice Age extinctions of large birds and mammals as the beginning of a continuum of extinctions caused by human activity which extends to the present. Dramatic losses of large mammal species follow a pattern of human dispersal across the globe from tens of thousands of years ago in Indonesia to just over 1,000 years ago in New Zealand, and over 20% of all bird species have become extinct within the past 1,100 years. Rates of extinction have accelerated in the past 50 years; current estimates include 3 species per hour and as many as 140,000 per year. In 2002, Harvard biologist E.O. Wilson predicted that if current rates of extinction continue, 50% of plant and animal species will be lost within the next 100 years – compared to hundreds of thousands or even millions of years for previous mass extinctions. Direct economic benefits include the potential to diversify our food supply, resources for clothing,shelter, energy, and medicines, a wealth of efficient designs which could inspire new technologies, models for medical research, and an early warning system for toxicity. Ecosystem services provided by biodiversity include ecosystem stability and productivity; maintaining and renewing soils, water supplies, and the atmosphere; nitrogen fixation and nutrient recycling; pollination, pest and disease control, and waste disposal. Less tangible but equally important are the cultural, aesthetic, and spiritual values and the importance of biodiversity to many modes of recreation. Finally, many people believe that biodiversity has intrinsic value, inherent in its existence. Human hunting, secondary effects on other species, disease carried and predation by exotic animals, and habitat destruction contributed to Ice Age extinctions. Habitat loss, including degradation and fragmentation, is the primary cause of extinction today; agriculture and deforestation continue to claim vegetated land and pollute both fresh and salt water seas.

Exotic species disrupt food chains and entire ecosystems to contribute to extinction. The modern equivalent to overkill, overexploitation of economically important species and ecosystems, threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species. Global climate change caused by the burning of fossil fuels disrupts weather patterns and, as it has throughout Earth’s history, holds the potential to force the extinction of carefully adapted species. Pollution of land, air, and water poisons life and destroys ecosystems. Between 1960 and 1999, the Earth’s human population increased from 3 billion to 6 billion people. Overpopulation combined with unequal distribution of resources dramatically intensifies pressures on biodiversity. Our daily activities and decisions can significantly help to protect biodiversity. After reducing consumption and reusing and recycling, careful consumption can help to conserve ecosystems. Local, seasonal products save energy costs for transportation. Durable and efficient products reduce long-term resource consumption.

Review Questions

1. Compare humans to other species in terms of resource needs and use and ecosystem service benefits and effects.
2. Define biodiversity and explain its three major components.
3. Give the three quantitative values for Earth's species diversity, and compare biodiversity across the Earth's surface and throughout the history of life.
4. Construct a chart showing why you consider biodiversity important. Your chart should include four categories (of the five presented in the chapter, or of your own choosing) and the 2-3 examples from each chapter that you consider most critical).
5. Analyze humans' role in extinctions by comparing the causes we think contributed to the Ice Age extinctions to the causes important to extinction today.
6. How might Tallgrass Prairies, the Brown Tree Snake, the Atlantic Cod, and the Peregrine Falcon serve as "poster species" to explain and highlight some of the causes of extinction?
7. "Reduce, Re-use, and Recycle" is so familiar to many people that it has lost much of its meaning. Yet it remains an efficient summary of the best conservation principles. Explain. Choose one new idea to add to these workhorses.
8. What two (or three) ecological principles can govern your food choices to help protect your health, biodiversity, and even global stability?
9. How does the concept of sustainable use differ from "reduce, re-use, and re-cycle"? How is it similar?
10. According to Barry Commoner, there are Four Laws of Ecology (as follows). Explain how his laws govern the way nature does – and humans should – use energy and material resources in order to protect biodiversity.
    - Everything is connected to everything else.
    - Everything must go somewhere.
    - Nature knows best.
    - There is no such thing as a free lunch.

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Vocabulary to Know

- air pollution - Alteration of the Earth's atmosphere by chemical, particulate, or biological materials.
- biodiversity hotspot - A biogeographic region which has lost at least 70% of its original habitat, yet contains at least 1500 endemic species of vascular plants.
- biodiversity - Variation in life – at all levels of organization: genes, species, and ecosystems.
- biological magnification (food chain concentration) - The process in which synthetic chemicals concentrate as they move through the food chain, so that toxic effects are multiplied.
- bionics - Engineering which uses biological organisms' design principles to develop efficient products.
- carbon sequestration - Process which removes CO_2 from the atmosphere.
- desertification - Degradation of formerly productive land (usually at least semi-arid).
- ecosystem diversity - The variety of ecosystems on Earth.
- ecosystem services - Indirect benefits provided by ecosystem processes, such as nutrient cycling and waste disposal.
- ecosystem - A functional unit comprised of living things interacting with their nonliving environment.
- endemic - A unique species found only within a certain area and nowhere else.
- epiphyte - Plant which grows on top of another plant.
- exotic (alien) species - A species introduced either intentionally or unintentionally to a completely new ecosystem – a non-native species.
- extirpation - Elimination of a species from a particular region of its range.
- genetic diversity - Variation among individuals and populations within a species.
- genetic pollution - Hybridization or mixing of genes of a wild population with a domestic or feral population.
- global warming - The recent increase in the Earth's average near-surface and ocean temperatures.
- greenhouse effect - The trapping by the atmosphere of heat energy radiated from the Earth's surface.
- keystone species - Species having a functional importance to ecosystem diversity and stability which far outweighs its numerical or mass importance.
- monoculture - Large-scale cultivation of single varieties of single species.
- natural resource - Something supplied by nature which supports life, including sources.
- pollution - Release into the environment of chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life.
- salination - Increase in salt levels in soils.
- species diversity - The number of different species in an ecosystem or on Earth.
- sustainable forest management - Forest management which ensures that the goods and services yielded from a forest remain at a level that does not degrade the environment or the potential for similar levels of goods and services in the future.
- sustainable use - Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their need

Chapter 11

Environmental Hazards & Toxicology

11.1 Introduction

This chapter takes a brief look at waste, hazardous waste and chemicals, and toxicology.

Chapter Objectives

- Understand different kinds of waste.
- Explain the differences between different kinds of chemical waste.
- Describe the ways that hazardous waste and chemicals affect human, animal and plant health.

11.2 Waste

Types of Waste:

Why should we care about waste? It is trash!Proper disposal of waste is important because inappropriate disposal of waste results in significant environment pollution which affects the well being of humans and wildlife.There are 4 types of waste

1. Municipal solid waste – waste from households
2. Industrial solid waste – waste from industries
3. Hazardous waste – waste that require special disposal due to toxicity
4. Waste water – from households (water from sinks, showers, toilets) or industries (water used for cleaning or cooling machines or products)

Waste Management

There are 4 components to waste management as listed below.1. Minimizing waste generated:

- The most important way to reduce waste is to take steps not to generate waste in the first place, because it
  - Avoids costs of disposal and recycling
  - Helps conserve resources
  - Minimizes pollution
  - Can save consumers and businesses money
- E.g. use reusable water bottles rather than disposable bottles, use reusable cloth shopping bag rather than plastic or paper bags, buy food or products with less packaging
- Read about ‘‘Reduce and Reuse” from the EPA website http://www.epa.gov/epawaste/conserve/rrr/reduce.htm

2. Composting waste:

- Composting is the conversion of organic waste into mulch, humus or fertilizer through the natural biological processes of decomposition
- Organically based waste from households, farms, food industries or restaurants can be composted rather than thrown out with the garbage
- Benefits include:
  - Reduces used landfill space
  - Enriches soil, helps soil resist erosion, encourages biodiversity
  - Reduces the need for chemical fertilizers
- Read about ‘‘Compositing” from the EPA website http://www.epa.gov/epawaste/conserve/rrr/composting/basic

3. Recovering and recycling waste materials:

- Paper, plastics, glass and metals are all materials that can be recycled
- The 3 chasing arrows in the recycling symbol represent the 3 steps of recycling

1. collection and processing of recyclables

2. use of recycled materials to manufacture new products
3. consumer purchase of recycled materials

- Recycling reduces the need to mine raw materials from the ground, and products made from recycled materials generally can be made with less energy
- Read about "Recycling" from the EPA website http://www.epa.gov/epawaste/conserve/rrr/recycle.htm

4. For waste material that cannot be recycled or composted, waste can be disposed of in landfills or incinerators:

- Landfills
  - Read about how landfills in the US from this website http://www.howstuffworks.com/landfill.htm/printable
  - Landfills are an eyesore (nobody wants one near their home) and take up a lot of space
  - The methane gas produced from decomposition of the waste in landfills can be collected and burned to generate electricity.
  - Landfills can leak, polluting the soil and water around the landfill. Also if soil is not used to cover the top of the landfill, waste can be blown by the wind to other locations
  - Hazardous wastes (mostly produced by industries, but also produced in households) are generally disposed of in special landfills. These landfills are located far from water and built with extra lining and leachate removal systems to prevent leakage of hazardous materials into the environment.
  - Ewaste is produced by households and businesses. Some examples of Ewaste are; cell phones, computers, printers, televisions, radios, refrigerators etc. They are considered hazardous wastes and should not be discarded into regular landfills for regular trash.
    * This is because Ewaste contains heavy metals that are toxic.
    * Ewaste should be sent to facilities that specialize in dismantling this type of waste so that recyclable components can be extracted and toxic components properly disposed.
    * Unfortunately, because some Ewaste contains gold components, they are often illegally shipped and dumped in developing countries where poor people extract the gold in a manner that harms their health and pollutes their environment.
    * Read about the problem of Ewaste from the Greenpeace website http://www.greenpeace.org/internatio e-waste-problem/where-does-e-waste-end-up/

- Incineration
  - Burning waste "destroys" about 80% of the waste, thereby reducing the waste volume; therefore this type of waste disposal is preferred in places where land is scarce.
  - Incineration is the correct disposal method for biologically hazardous waste (or biohazards) , e.g. waste from hospitals like syringes with human blood or other human biohazards).
  - Burning waste releases air pollutants that are harmful to humans and wildlife. However, most of these air pollutants can be removed by installing "scrubbers" in the incineration chamber of chimneys. The ash left after the burning is toxic and needs to be disposed of properly.
  - Waste can burned in incineration plants to generate electricity. Read about waste-to-energy plants from this website http://www.ocrra.org/trash_wte.asp

11.3 Environmental Hazards

Types of environmental hazards:

Environmental health is defined as the assessment of environmental factors that influence human health and quality of life, and steps taken to avoid environmental hazards or minimize its effects.There are 4 major types of environmental hazards:

1. Physical – e.g. Earthquakes, volcanoes, fires, floods, droughts, lightning, hurricanes, landslides,
2. Chemical – synthetic (man-made) (e.g. pesticides, disinfectants, pharmaceuticals) or natural chemicals (e.g. venom from cobras, urushiol in poison ivy)
3. Biological – e.g. bacterial infections from E. coli, parasites like malaria, viruses like the flu
4. Cultural – lifestyle based e.g. smoking, diet and nutrition, activity level

Indoor and Outdoor Chemicals

People who live a modern lifestyle are usually exposed to a variety of indoor and outdoor chemical hazards. Synthetic chemicals are even more pervasive in our environment due to widespread usage

- There are 100,000 chemicals are on the market today.
- Very few chemicals have been thoroughly tested.
- We don't know the effects, if any, they have.
- When the chemicals accumulate and mix in our bodies, they could interact to become more toxic
- Every human carries traces of industrial chemicals in their blood and tissue.

Indoor hazards include:

- Smoke – cigarette or cigar smoke, smoke from indoor wood stoves.
- Lead in paint and lead in pipes which end up in drinking water. Lead exposure especially to young children leads to brain and organ damage, and even death.
- Radon is a toxic radioactive gas that comes from naturally occurring uranium or radium in the ground.
- Asbestos used for insulation in buildings – exposure leads to lung cancer.
- Plastic containing toxins are used to make furniture, appliances, utensils or toys.
  - Polybrominated diphenyl ethers (PBDEs) – a chemical used in computers, televisions, plastics and furniture. It persists and accumulate in the body, affecting the thyroid, nervous system developmentes, the brain and causes cancer.
  - Biphenol A (BPA) – used in many types of plastic containers and plastic bottles, affects the thyroid, causes birth defects, increases breast cancer risks.Many soft toys for infants contain phthalates. Photo from:http://www.flickr.com/photos/personaldork/3803731863/
  - Pthalates – used to make plastic toys soft and used to enhance fragrances in cosmetics, negatively affects male fetuses.
  - When you look at the bottom of a plastic container ,it shows a number in a triangle (numbers range from1 to 7). This number indicates the plastic type. Plastics numbered 3 and 7 contain BPA.
  - Microwaving food in plastic containers or plastic lids releases chemicals in the plastic into your food. Placing hot foods in plastics has the same toxic effect. The best containers for heating food or storing hot food are glass or porcelain.

Outdoor hazards include:

- Automobile exhaust containing toxic chemicals that harm our respiratory system, eyes and accumulate toxins in our bodies
- Industrial pollution containing toxic chemicals that harm our respiratory system, eyes and accumulate toxins in our bodies
- Pesticide and herbicide drift – pesticides carried by the wind to non-farm areas expose us and wildlife to toxins meant to kill insect pests
- Residue on food – We accumulate toxins when we consume plants that have pesticide or herbicide residue. If we consume animals that are exposed to pesticide or herbicide drift we can also be poisoned indirectly.
- Water borne chemicals – Many substances dissolve in water and hence can be carried long distances by water. Synthetic chemicals from land that are soluble in water are carried by runoffs after rainstorms into fresh water rivers, ponds, lakes or to the oceans. When we consume this water or swim in it, we become exposed to this mix of chemicals originating from different locations.
- Read about how pharmaceutical drugs end up in our drinking water http://www.cbsnews.com/stories/2008/03/1

Types of Toxicants that Affect Health

- Carcinogens: cause cancer
- Mutagens: cause DNA mutations that can lead to severe problems, including cancer
- Teratogens: cause birth defects, e.g. alcohol, sedative drug thalidomide Birth defect caused by thalidomide .https://cms.psu.edu/section/content/default.asp?WCI=pgDisplay&WCU=CRSCNT&ENTRY_-ID=56E1E61A289445988555F2CD6002EA62
- Neurotoxins: assault the nervous system, e.g. heavy metals, pesticides, chemical weapons like mustard gas
- Allergens: over-activates the immune system, but not universal toxicant, e.g. pollen, dust, mold
- Endocrine disruptors: interfere with the endocrine (hormone) system, some mimic real hormone molecules, e.g. pesticides atrazine mimic sex hormones and result in feminized and infertile male frogs and pesticide DDT causes reproductive abnormalities in alligators


See this animation about biomagnification, click here.

11.4 Biomagnification of Toxins

- 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.
  - read from the US Food and Drug administration website for the mercury level of different fish species (avoid those with the highest mercury) http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm115644.htm

Chemicals are an unavoidable part of modern day life for people living in many parts of the world. The problem is that many nations use the "innocent until proven guilty" principle when it comes to allowing a new chemical to be sold to the public as paints, cosmetics, pesticides, insecticides, plastics, furnishings, electronics etc.

- This means that most of the chemicals we use today have not been tested for toxicity to humans and other living things.
- The threat of lawsuits and scandal will prevent manufacturers from selling chemicals that have immediate toxic effects (acute exposure) (e.g. if you became very ill after painting your house)
- But nothing stops them from selling chemicals that have less obvious long-term toxicity (chronic exposure) because it would be hard to trace this type of toxicity back it its sources. (e.g. if the paint in your house contains lead and it slowly poisons you so that after 20 years you suffer from liver failure, it is not obvious to you that your illness was caused by the paint)
- Therefore it is important to educate ourselves about these environmental hazards and take steps to minimize our exposure and risk.

11.5 End of Chapter Review & Resources

Chapter Summary

Hazardous waste and chemicals can cause several health problems in ecosystems, humans, animals and plants. Through the process of biomagnification, even small amounts of these toxins in the environment can increase in quantities in animal tissue.

Review Questions

1. What is biomagnification and how does it work.
2. What are the different kinds of hazardous waste?
3. What are the different kind of hazardous chemicals?
4. What are the different kinds of toxins that cause health problems?

Vocabulary to Know

- **Biomagnification**
- **Hazardous chemical**
- **toxin**

Chapter 12

Land Use & Degradation

12.1 Introduction

The concept of land use (i.e., the way a particular piece of land is utilized by humans and other living organisms), seems at first glance a simple and straightforward subject on the surface. Humans use land to build cities where they live (residential land) and work (commercial land). They use land for growing crops and raising livestock (agricultural land) for food. Forestland provides fuel for energy and lumber for building. Humans use land for play (recreational land) and set some of it aside as exclusive wildlife habitat (wilderness land). But no matter how land is used by humans and other living species, humans ultimately decide how land is used. Given the nature of humans, land use involves a complex interplay of environmental parameters, economic needs and often politics.Population increases in semi-arid and arid regions and changes in regional climate often lead to land degradation and sometimes to the collapse of societies in these regions. The problem is as old as civilization. Societies living in the western areas of what is now the Saharan desert of Egypt collapsed when the region dried out around 5,000 to 3,000 BC. The Anasazi society collapsed due to over population and land abuse between 1130 AD and 1300 AD. Now Mongolia and China, parts of the middle east and the US Southwest face similar problems.

Chapter Objectives

- Outline the factors involved in land use planning.
- Compare urban development patterns under traditional and smart-growth planning schemes.
- Describe the types and uses of croplands and the causes and consequences of their loss.
- Explain the purposes and benefits of designated recreational and wilderness lands.
- Define desertification and how it occurs.
- Compare and contrast desertification issues around the world.
- Understand how overuse of the land and deforestation can lead to desertification.
- Examine the ecological implications of desertification.
- Review examples of desertification.
- Review a case study of desertification, the ramifications, and the methods used to remediate it.
- Discuss some natural resources used to make common objects.
- Describe some ways to conserve natural resources.

12.2 Land Use

What negative connotations we give to soil resources in our daily conversation! Hands are ‘‘dirty;” clothing is ‘‘soiled.” Yet the formation of soils require thousands and even millions of years of physical, geological, chemical, and biological processes. Soil’s complex mixture of eroded rock, minerals, ions, partially decomposed organic material, water, air, roots, fungi, animals, and microorganisms supports the growth of plants, which are the foundation of terrestrial ecosystems (Figure below). Soil is a balanced intersection of air, water, and land resources, sensitive to changes in any one element. We use soils for agriculture, gardening, landscaping, earth sheltered buildings, and to absorb waste from composting and septic drain fields. Peat, an accumulation of partially decayed plant material, can be burned for energy.

Soils can assimilate and remove low levels of, thus it is useful for waste treatment. Not surprisingly, high levels of contamination can kill soil microorganisms, which help to accomplish this service. Toxics from industry, underground storage tanks, pesticide use, and leaching from landfills and septic tanks contaminate soils across the globe. Contaminated soils endanger human and ecosystem health. In 1980, after several years of health concerns and protests, the U.S. Government relocated and reimbursed 800 families from the Love Canal housing development built atop a landfill which had ‘‘disposed of” 22,000 tons of toxic waste from Hooker Chemical and Plastics Corporation.

Increased awareness of the problems of abandoned toxic waste sites led to the passage later that year of Superfund legislation, which holds polluters accountable for effects of toxic waste, and taxes chemical and petroleum industries to pay for cleanup of sites where responsible parties cannot be identified. As of early 2007, the EPA listed 1,245 Superfund sites; 324 are delisted, and 66 new sites are proposed.

In general, developing countries lag behind in identification, cleanup, and prevention.

Agriculture, as one of the largest land uses, has altered soils in a number of ways. When we harvest crops repeatedly from soil, we remove basic ions such as Calcium, Magnesium, Potassium, and Sodium. One result is acidification, which lowers soil fertility and productivity. Acid rain and the use of nitrogen fertilizers accelerate acidification, and acid rain can increase soil contamination.Irrigation can degrade soils through salination – the accumulation of salts. High concentrations of salt make it difficult for plants to absorb water by osmosis, so salination reduces plant growth and productivity, and can lead to desertification (degradation of formerly productive land – usually at least semi-arid) and soil erosion.

Agriculture, deforestation, overgrazing, and development can remove vegetation to cause unnatural levels of erosion by wind and water. In the U.S., erosion forced its way into public awareness during the 1930s after drought compounded exposed soils. The famous Dust Bowl resulted in the loss of at least 5 inches of topsoil from nearly 10 million acres of land and the migration of 2.5 million people out of the Great Plains. Today in the U.S., contour plowing, cover crops, terracing, strip farming, no-till farming, reforestation, and better construction practices prevent some soil erosion but the USDA reports that 1.6 billion metric tons of topsoil were lost annually between 1997 and 2001. Since Great Plains agriculture began some 200 years ago, the U.S. has lost one-third of its topsoil. Alarming rates of slash-and-burn agriculture in tropical forests expose thin soils to erosion, and development in China sends 1.6 billion tons of sediment annually into the Yellow River.

Residential and Commercial Land Use

About half of the earth’s human inhabitants live in urban areas. These urban areas include residential land for homes and commercial land for businesses. The number of people living in urban areas continues to grow each year, and as a result, the amount of land used for residential and commercial use is also increasing. Cities in the United States usually require that residential land be separated from commercial land. This has been a factor in the development of urban sprawl, the low-density housing developments surrounding many cities and towns.

A city grows in three basic ways: concentric, sector and multiple nuclei. In the **concentric city model**, the city develops outward from a central business district in a set of concentric rings (i.e., New York City). Commercial areas are concentrated in the central district, while the outer rings are typically residential areas. A **sector city** develops outward in pie-shaped wedges or strips (i.e., the Silicon Valley region south of San Francisco).

PHOTO CREDITS: VAHE PEROOMIAN

RESIDENTIAL AND COMMERCIAL LAND USE

This type of growth results when commercial and residential areas are built up along major transportation routes. A **multiple-nuclei** city evolves with several commercial centers or satellite communities scattered over the urban region instead of a single central business district. The Los Angeles metropolitan area is a good example of a multiple-nuclei city.

Much of the land converted to residential and commercial use in cities was formerly used for agricultural purposes or consisted of ecologically important areas such as wetlands. Cities are built on such land as a result of conventional land use planning, which encourages substantial urban growth for purely economic reasons (i.e., as a means of increasing the tax base). Unfortunately, when economic factors are the only one considered, degrading effects to the environment are generally disregarded. Some cities now use a smart-growth model in which development of urban areas is designed to strike a balance between economic needs and safeguarding the environment.

One city design approach used to control urban growth is establishing **greenbelts** around the city peripheries. Greenbelts provide habitat such as forest areas for animals and open space for human recreation, while blocking the outward growth of the city. Another method used to lessen the effects of urban sprawl is the **cluster development model** for new residential areas. In this design housing is concentrated in a restricted portion of a tract, leaving the rest of the land in a relatively natural state with trees, open space and waterways.

Agricultural and Forest Land Use

Less than half of the land area in the world (and in the United States) is used for agriculture. The majority of agricultural lands are **rangeland** or **pasture**. Rangelands are unsuitable for growing grain crops for a variety of reasons: the land may be too rocky or too steep, or the climate may be too cool or too dry. Livestock grazing is the major agricultural use of rangeland and pasture. Together, rangeland and pasture comprise about 35 percent of non-federal land (526 million acres) in the United States. Most of the nation's rangelands are in vast areas of the western states with arid to semi-arid climates. Pastures, which are smaller managed grassy areas, are found on farms throughout the United States.

Croplands are important because they account for the bulk of food production. About 20 percent of the land in the United States (about 400 million acres) is croplands, with the highest concentrations in the central United States. About 70 percent of all cropland in the United States is classified as prime farmland.

Prime farmland is land that has a growing season, a water supply from precipitation or irrigation, and sufficiently rich soil to sustain high yields when managed according to modern farming methods. Cropland may become prime farmland with the addition of the irrigation or flooding protection needed to sustain high yields. Farmlands in the eastern and southern United States are generally smaller and produce a greater variety of crops than those in the Corn Belt and Great Plains, where a few major grain crops predominate.

In countries throughout the world, agricultural land is being lost for various reasons. Some land is being lost to other uses such as housing developments, commercial developments and roads. Unfortunately, this change in use is taking from us much prime agricultural land. In the United States, federal programs exist that encourage farmers to stop farming agricultural lands defined as sensitive, which pose a risk of environmental degradation.

In an attempt to help preserve prime farmland in the United States, some local and state governments and private organizations have programs to purchase easements on cropland that restricts nonagricultural use.

Such croplands are temporarily or permanently retired from active production and are planted with perennial grasses or trees. Millions of acres of agricultural land in semiarid regions are lost each year due to a phenomenon called **desertification**. This occurs when once-productive land becomes too arid for agricultural use because of climate change or poor land management (i.e., overgrazing of rangeland, erosion of croplands).

Years ago, the standard practice for replacing lost agricultural lands or increasing overall production in many countries was to develop new farmland from formerly uncultivated land.

But now, areas of potentially arable land are shrinking in most countries. Most of the uncultivated land that does remain is marginal, with poor soils and either too little rainfall or too much.

Tropical rainforests are being logged at a fast rate to provide farmland. However, soils in rainforests are nutrient poor and prone to erosion by frequent tropical rains. Destruction of rainforest regions may also contribute to global environmental problems such as global warming. Forests of all kinds are very important ecologically. As major biomes, they provide a habitat for living species and support the food webs for those species. Forests play an environmental role by recycling nutrients (i.e., carbon, nitrogen) and generating oxygen through photosynthesis. They even influence local climatic conditions by affecting air humidity through evaporation and transpiration processes. Economically, forests are also very important.

Humans have utilized forests for thousands of years as a source of energy (i.e., fuel), building materials (lumber) and pulpwood for paper, and these uses remain important. When forestlands hold valuable mineral resources beneath them, they may be cleared to provide access to the minerals.

The United States Forest Service defines forestlands as lands that consist of at least 10 percent trees of any size. They include: transition zones (such as areas between heavily forested and nonforested lands) and forest areas adjacent to urban areas. In the western states they include pinyon-juniper and chaparral areas. Forests cover about one-third of the United States, which is about 70 percent of their extent when European settlement began in the 17th century. About 42 percent of U.S. forestlands are publicly owned. Of these, about 15 percent are in national parks or wilderness areas and are thus protected from timber harvest.

Other public forestlands are managed for various uses: recreation, grazing, watershed protection, timber production, wildlife habitat, and mining. Forests in the western states are predominantly publicly owned, while those in eastern states are predominantly privately owned.

Forests can be classified by their relative maturity. **Old-growth forests** have been undisturbed for hundreds of years. They contain numerous dead trees and fallen logs which provide species habitats and are eventually recycled through decay. **Second-growth forests** are less mature and occur when the original ecological community in a region is destroyed, either by human land-clearing activities or by natural disasters (i.e., fires, storms, volcanic eruptions). Humans sometimes create artificial forests in the form of tree farms. Usually only one tree species is planted in a tree farm. After maturing enough to be of economic value, the trees are harvested and new trees planted in their place.

Forest trees can be harvested by different methods: selective cutting, seed-tree cutting, strip cutting and clear cutting. Most of these methods have distinct effects on the ecology of the harvested area. Selective cutting is usually least damaging to the local ecosystem. In this method of harvesting, trees that are moderate to fully mature are cut singly or in small groups. This approach allows most of the trees to remain, which helps maintain habitats and prevent soil erosion and allows uninterrupted recreational use. However, in tropical forests when only the biggest and best trees are removed, selective cutting can lead to significant ecosystem damage. Because the canopy of a tropical forest is thick and intertwined, the removal of one large tree damages a considerable area around it.

Other harvesting methods involve removal of most or all of the trees in a given area. **Seed-tree cutting** removes most of the trees in an area, leaving only a few scattered trees to provide seeds for regrowth.

The remaining trees provide some habitat for animals and help reduce soil erosion. However, when seed trees are cut, the forest loses its diversity and is often converted to a tree farm.

Clear cutting and **strip cutting** both remove all trees in an area. Clear-cutting usually involves large areas of land resulting in the concomitant destruction of a large area of wildlife habitat. The logged areas are susceptible to severe erosion, especially when the clear cutting occurs on slopes. With strip cutting, trees are removed from consecutive narrow strips of land. The strips are removed over a period of years and as a result some trees (uncut or regrowth) are always available for animal habitat. The cut area is partially protected from erosion by the uncut or regrowth trees in the adjacent areas.

Recreational and Wilderness Land Use

An important human-centered benefit of undeveloped land is their recreational value. Every year, millions of people visit recreational lands such as parks and wilderness areas to experience attractions of the great outdoors: hiking among the giant sequoias in California, traveling on a photo safari in Kenya or just picnicking at a local county park. Besides providing people with obvious health benefits and aesthetic pleasures, recreational lands also generate considerable tourist money for government and local economies.

The United States has set aside more land for public recreational use than any other country. Several different federal organizations provide lands for recreational use: the National Forest System, the U.S. Fish and Wildlife Service, the National Park System and the National Wilderness Preservation System. The National Forest System manages more than 170 forestlands and grasslands, which are available for activities such as camping, fishing, hiking and hunting.

PHOTO CREDITS: VAHE PEROOMIAN

RECREATIONAL AND WILDERNESS LAND USE

The U.S. Fish and Wildlife Service manages more than 500 National Wildlife Refuges, which not only protect animal habitats and breeding areas but also provide recreational facilities. The National Park System manages more than 380 parks, recreation areas, seashores, trails, monuments, memorials, battlefields and other historic sites. The National Wilderness Preservation System manages more than 630 roadless areas through the aforementioned government services as well as through the Bureau of Land Management.

The **National Park System** consists of more than 80 million acres nationwide. The largest national park is Wrangell-St. Elias National Park and Preserve in Alaska with over 13 million acres. California has eight national parks: Channel Islands, Death Valley, Joshua Tree, Lassen, Redwood, Sequoia, Kings Canyon and Yosemite.

Many national parks such as Yosemite, Yellowstone and the Grand Canyon are such popular recreation destinations that the ecosystems of those parks are being severely tested by human activities.

Every state has also set aside significant amounts of land for recreational use. The California State Park System manages more than one million acres of parklands including: coastal wetlands, estuaries, scenic coastlines, lakes, mountains and desert areas. California's largest state park is Anza-Borrego Desert State Park, which is the largest state park in the United States with 600,000 acres. The stated mission of the California State Park System is: "To provide for the health, inspiration and education of the people of California by helping to preserve the state's extraordinary biological diversity, protecting its most valued natural and cultural resources and creating opportunities for high-quality outdoor recreation."

This is the basic goal of all recreational lands: to manage and conserve natural ecosystems, while supporting a sustainable and balanced level of human use of those areas. Unfortunately, it is a goal which is sometimes difficult to achieve due to the increasing popularity and use of recreational lands.

The "Wilderness Act of 1964" created the world's first wilderness system in the United States. Presently, the **National Wilderness Preservation System** contains more than 100 million acres of land that will forever remain wild. A wide range of recreation, scientific and outdoor activities are available in wilderness lands. Mining operations and livestock grazing are permitted to continue in certain wilderness areas where such operations existed prior to an area's designation. Hunting and fishing are also allowed in wilderness areas (except in national parks).

For most people, wilderness lands provide a means for various forms of recreation: hiking, horseback riding, bird watching, fishing, and hunting. People can escape the stress of modern-day life and enjoy an undisturbed look at nature. Wilderness lands provide an essential habitat for a wide array of fish, wildlife, and plants, and are particularly important in protecting endangered species. For scientists, wilderness lands serve as natural laboratories, where studies can be performed that would not be possible in developed areas.

Several other types of public lands complement the designated wilderness land system. These include: national forest roadless areas, national trails system, natural research areas and state and private wilderness lands. The national forest roadless areas consist of millions of acres of wild, undeveloped land without roads that exist on National Forest land outside of designated wilderness lands.

The "National Trail System," established by Congress in 1968, includes trails in wilderness areas and other public lands. **Research Natural Areas** located throughout the country on public lands serve as outdoor laboratories to study natural systems. They are intended in part to serve as gene pools for rare and endangered species and as examples of significant natural ecosystems. Some wilderness lands are maintained by states or private organizations. For example, the state of New York has long preserved a region of the Adirondacks as wilderness.

On an international level, important wilderness lands have been designated by the United Nations through its "Man and the Biosphere Program." This program was established in 1973 to protect examples of major natural regions throughout the world, and provide opportunities for ecological research and education.

Biosphere reserves are organized into three interrelated zones: the **core area**, the **buffer zone** and the **transition area**. The core area contains the landscape and ecosystems to be preserved. The buffer zone is an area where activities are controlled to protect the core area. The outer transition area contains a variety of agricultural activities, human settlements and other uses. Local communities, conservation agencies, scientists and private enterprises that have a stake in the management of the region work together to make the reserves work. Mt Kenya in Africa and the Galapagos Islands are examples of wilderness areas protected under this provision.


See this animation about Tree Harvesting: Click here.

12.3 Land Degradation in Arid Regions

Population increases in semi-arid and arid regions and changes in regional climate often lead to land degradation and sometimes to the collapse of societies in these regions. The problem is as old as civilization. Societies living in the western areas of what is now the Saharan desert of Egypt collapsed when the region dried out around 5,000 to 3,000 BC. The Anasazi society collapsed due to over population and land abuse between 1130 AD and 1300 AD. Now Mongolia and China, parts of the middle east and the US Southwest face similar problems. For example: see Trends of Desertification and its Rehabilitation in China.

> Plato: Attica (Athens) was no longer cultivated by true herdsmen, who made husbandry their business, and were lovers of honor, and of a noble nature. As a result Attica had become deforested, the soils depleted, and there are remaining only the bones of the wasted body –all the richer and softer parts of the soil having fallen away. From US Department of Agriculture web page on Land Degradation and Desertification.

Some Definitions

Land Degradation

> Land degradation means the reduction, or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland or range, pasture, forest and woodlands, resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation. From United NationsConvention to Combat Desertification Item (f).

Others point out that land degradation in not limited to drylands. Cutting down rainforests, such as deforestation of the Amazon, also leads to land degradation. More broadly, it can be defined as:

> Any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience. From Global Environmental Facility.

Desertification

> Desertification is the degradation of land in arid, semi-arid, and dry sub-humid areas. It is caused primarily by human activities and climatic variations. Desertification does not refer to the expansion of existing deserts. It occurs because dryland ecosystems, which cover over one third of the world's land area, are extremely vulnerable to over-exploitation and inappropriate land use. Poverty, political instability, deforestation, overgrazing, and bad irrigation practices can all undermine the land's fertility. From Food and Agricultural Organization web page on Desertification.

Thus desertification is a type of land degradation. The degradation converts useful but arid lands to less useful desert. It is characterized by:

1. Declining groundwater,

2. Increased erosion,
3. Disappearance of native vegetation,

Areas Vulnerable to Desertification

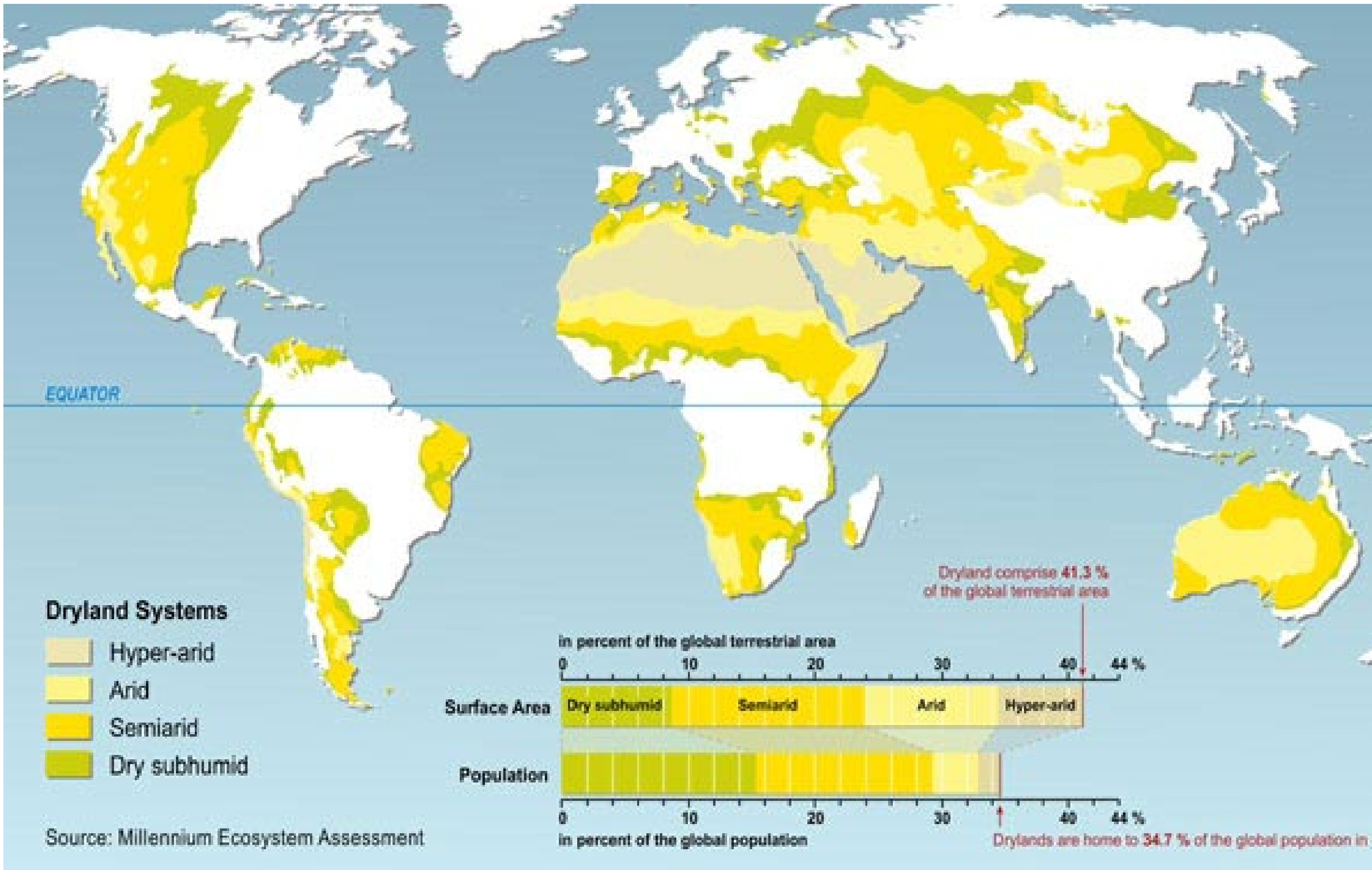
> Drylands cover about 41% of Earth's land surface and are home to more than 38% of the total global population of 6.5 billion. Some form of severe land degradation is present on 10 to 20% of these lands, the consequences of which are estimated to affect directly some 250 million people in the developing world, an estimate likely to expand substantially in the face of climate change and population growth. From Reynolds et al, 2007.

Table 12.1:

Region			**Semi Arid**		**Dry Sub-Humid**			%	
Asia (Incl. Russia)	6,164	13	7,649	16	4,588	9	18,401	39	1,444,906
Africa	5,204	17	5,073	17	2,808	9	12,933	43	267,563
Oceania	3,488	39	3,532	39	996	11	8,016	89	140,586
North America	379	2	3,436	16	2,081	10	5,896	28	86,990
South America	401	2	2,980	17	2,233	13	5,614	32	59,323
C. America & Caribbean	421	18	696	30	242	10	1,359	58	31,719
Europe	5	0	373	7	961	17	1,339	24	6,960
	15,910	**12**	**23,739**	**18**	**13,909**	**10**	**53,558**	**41**	**2,038,047**

Land area: millions of square kilometers. Population: thousands. From White and Nackoney (2003)

The vulnerable areas are mostly in mid-latitudes near 30 degrees of latitude.



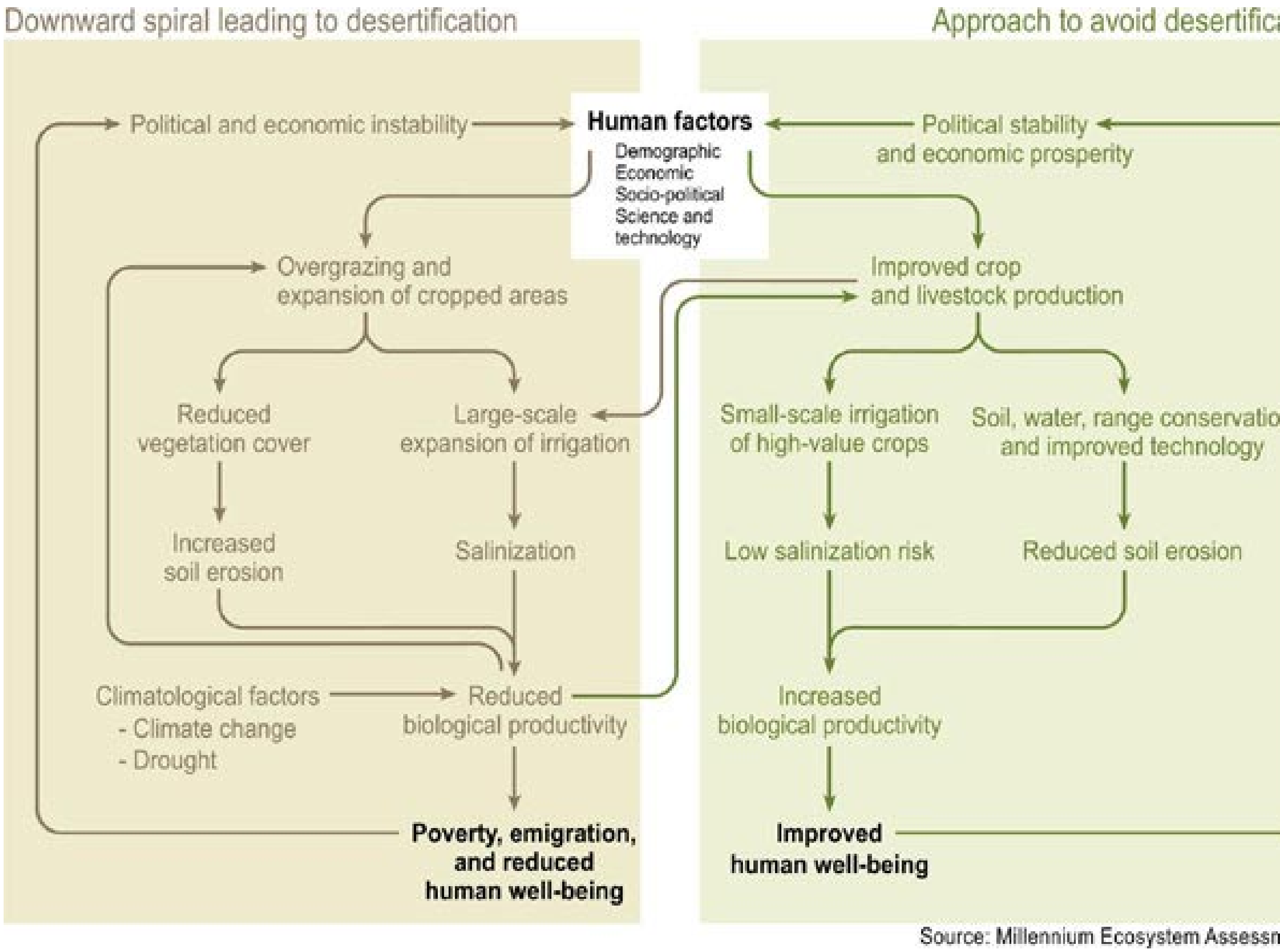
Global map of dryland areas. Click on the map for a zoom. From Millennium Ecosystem Assessment (2005): Appendix A.

Causes of Degradation

Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system. Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes, which are not fully understood. Interactions between the two systems determine the success or failure of resource management programmes. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability). From Climate and Land Degradation.

A. Human Systems

Degradation is due to a complex mix of many types of human activity, including many interlocking threads of the human societal system.



Schematic graphic showing how drylands can be developed in response to changes in key human factors. Left: Developments that lead to a downward spiral of desertification. Right: Developments that can help avoid or reduce desertification. In this development, land users respond to stresses by improving their agricultural practices on currently used land. This leads to increased livestock and crop productivity, improved human well-being, and political and economic stability. Both development pathways occur today in various dryland areas. From Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-Being. Desertification Synthesis.

1. **Population Increases.** Nomadic peoples lived in harmony with drylands for thousands of years. Land degradation begins when populations increase to the point that the land can no longer sustain the people. For example, the population of Maradi Province, Niger in the west African sahel increased from 0.56 million in 1960 to 1.39 million in 1998 accompanied by migration of farmers into northern areas where farmland was free (Reynolds and Smith, 2007). As a result— Niger is a country with chronic food shortages. Every year, during the "hunger season," there is a significant increase in the number of children aged five years and under who will face acute malnutrition. The intake of food, both in terms of quality and quantity, is insufficient to meet the nutritional needs of young children. This, combined with diseases such as malaria, diarrhea, and acute respiratory infections, causes high levels of death among children in the country. From Doctors Without Borders
2. **Unsustainable Agricultural Practices** Large populations relative to what the land can support

leads to attempts to grow too many crops. Cropland in drylands needs time to recover from growing crops when no fertilizer is used. if the land is replanted to soon, fertility declines, loss of soil humus, and poorer soils. If the crops are irrigated without good management practices, the soil becomes too salty, and crops can no longer be grown.

3. **Overgrazing** Too many people trying to raise too many animals leads to overgrazing. This removes grass cover and vegetation, causes soil compaction, and leads to high rates of wind and water erosion. Overgrazing is made worse by the conversion of traditional rangelands to crop lands, cities, roads, and industrial sites. All reduce the acreage available for grazing.
4. **Deforestation** People use wood for cooking and heating. When the population is too large, forests are destroyed to obtain wood. Forests are also cut or burned to make way for crops (slash-and-burn agriculture),or to obtain wood for export.
5. **Bad Government** Unsustainable agriculture, overgrazing, and deforestation are the result of poor planning, laws, and regulations by governments. Wise governments recognize the importance of the land and plan appropriately. Poor governments do not. Laws, economic policy, land rights, and the wisdom of government officials are all inter-related. The type of government is much less important. Strong central governments have led to wise use of the land (Japan under the Tokugawa rule in the 17th century) or to disaster (the Soviet Union in the 20th century). For example, the Soviet Union's policy to expand agriculture into drylands, by diverting water from the Amu Darya and Syr Darya rivers into the desert for irrigation, led to widespread land degradation and drying up of the Aral Sea. Indeed, the only large-scale ecosystem collapse of modern times – the case of the Aral Sea – is intimately tied to a chain of decisions emanating from the former Soviet State, translated into large, inefficient irrigation systems on the two rivers feeding the sea. From IGBP Global Land Project.
6. **Poverty** Poverty reduces the options for improving land use, and aggravates degradation. Poor nations seek income by exporting crops or minerals to developed countries. The push to increase cropland leads to unsustainable agricultural practices.
7. **Globalization** It removes barriers to the trade in commodities such as crops or minerals. Developments in one part of the world influence developments in other parts. As a result, European demand for crops leads to increased farming in African drylands, leading to degradation.
8. Inappropriate Technology and Advice, For example, the Soviet Union paid for the Aswan High Dam, which reduced the flooding of the Nile valley in Egypt, reducing the fertility of the land, and leading to the encroachment of the Mediterranean Sea into the Nile delta.
9. **Colonial Legacy.** Country boundaries set up during colonial times sometimes separated areas used by nomadic, pastoral people. Governments then prohibited the free movement across the boundaries, forcing the nomads to live in one area. Nomads followed rain, moving to new grasslands as needed. Once movement was restricted, and they were forced to remain in an area after grass was gone, land degradation resulted. National boundaries left from colonial times can also disrupt rational use of water. An upstream country may overuse water rights, leaving little for downstream countries, leading to land degradation downstream.
10. **Lack of Tenure (private ownership of land).** Nomadic societies that traditionally lived in drylands held land in common, leading to the tragedy of the commons as populations increased.
11. **War and Civil Unrest** It is hard to care for the land during war. High population densities leading to a lack of resources leads to civil strife and war. Today it is Darfur in the Sudan and many regions in the middle east. In the past it was in Rwanda and the Congo. When resources are scarce, one region may try to steal from another through war, or to kill local competitors for the resource, especially if the scarce resource is food necessary to live.

B. Natural Systems

Land degradation is also due to extended periods of drought or climate change leading to a permanent reduction of rainfall or timing of rains. Before large populations moved into arid lands, the natural variability of rainfall and climate change caused deserts to grow and shrink. Of the two primary causes of degradation, human activity, especially political ineptitude dominates. Drought mainly amplifies the human influence.

Drought

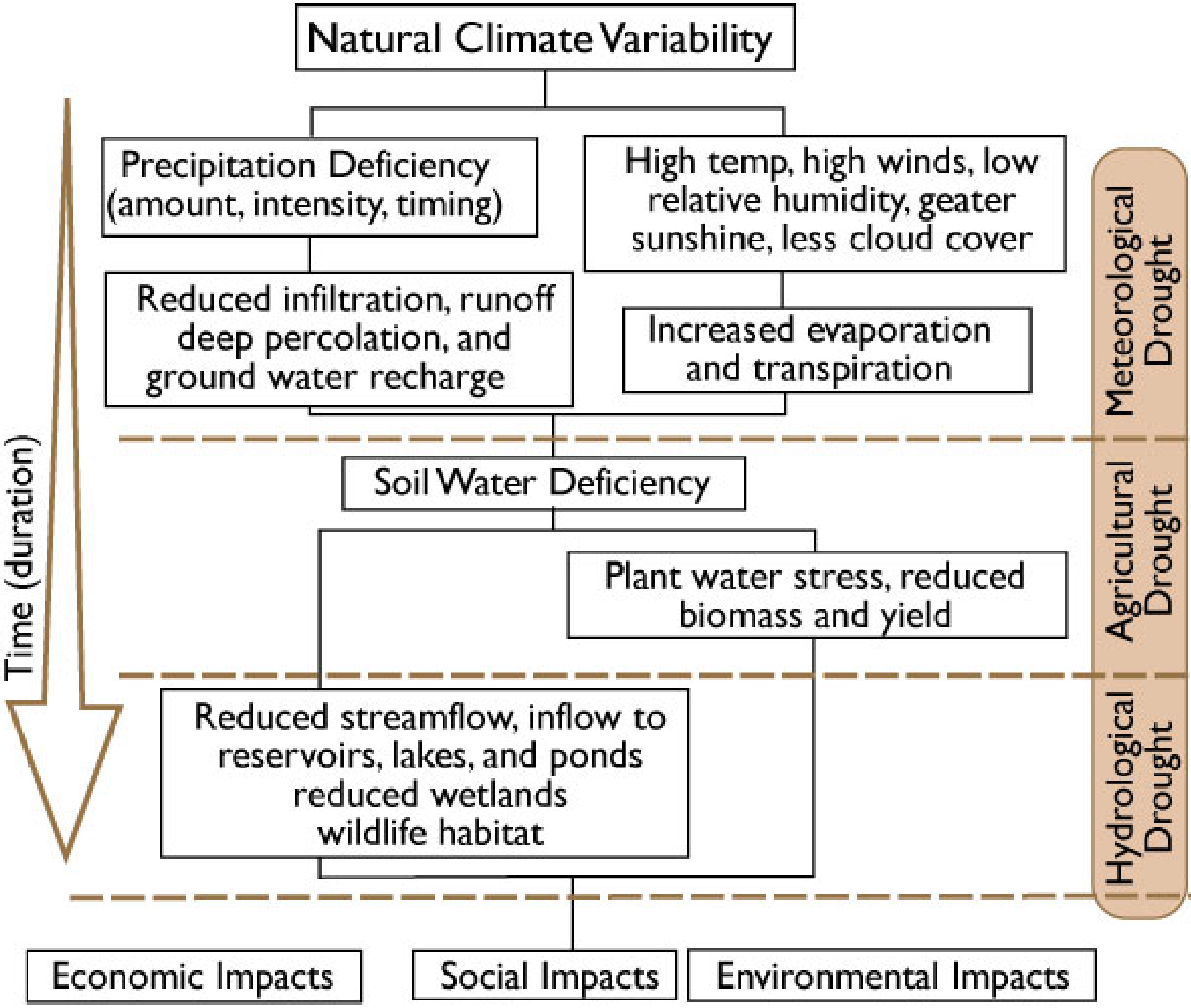
> Drought is a normal, recurrent feature of climate, although many erroneously consider it a rare and random event. It occurs in virtually all climatic zones, but its characteristics vary significantly from one region to another. Drought is a temporary aberration; it differs from aridity, which is restricted to low rainfall regions and is a permanent feature of climate. From National Drought Mitigation Center's web page on What is Drought?

There are several important types of drought, each of which depends on the duration of the reduction of precipitation:

1. **Meteorological drought**, which is determined by the rainfall, temperature, and evaporation, including evapotranspiration. The Palmer Drought Severity Index and the Standardized Precipitation Index are both widely used indices in this category.

    (a) Rainfall is usually very irregular in semi-arid regions. Rain tends to fall in some seasons, but not in others. There are large variations in rainfall from year to year.
    (b) Higher temperatures cause rapid evaporation of water from the surface and from lakes.

2. **Agricultural drought**, which is determined by soil water availability and plant stress.
3. **Hydrological drought**, which is determined by stream flow, storage in reservoirs, groundwater levels, soil moisture, and snow pack.



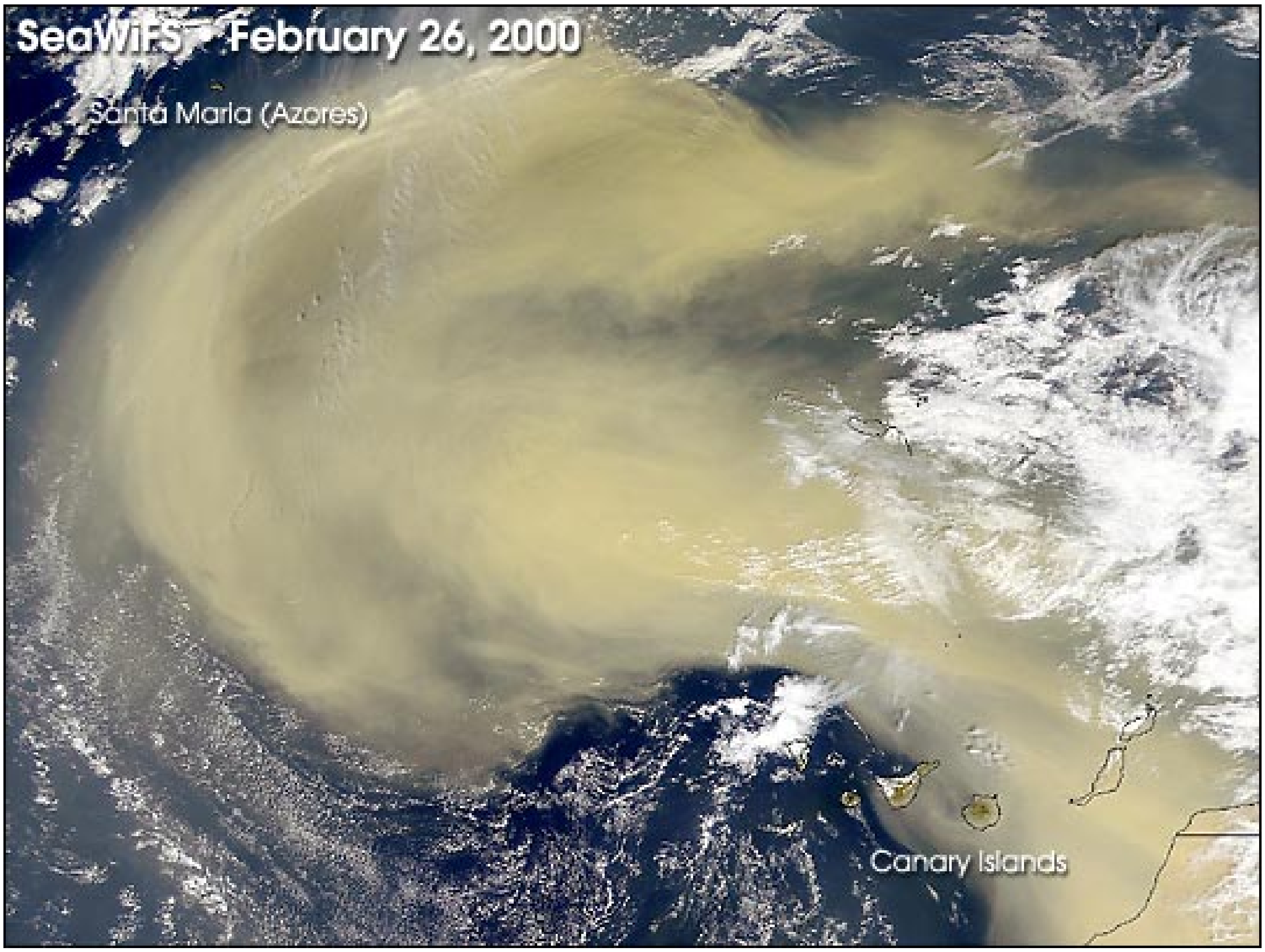
From National Drought Mitigation Center's web page on What is Drought?

Semi-arid and arid lands are especially susceptible to drought because rainfall in these regions is much more variable than in wetter areas.

12.4 Aeolian Transport of Sand and Dust

Dust storms have occurred throughout history. But as regions of land degradation expand, storms become worse with many important influences. And the dust carries many pollutants introduced into the soil by the land degradation.

Dust Storms Influence Weather And Climate By Changing Albedo Of Earth



This image of a major dust storm blowing dust from the Sahara out over the Atlantic. The dust increases the amount of solar radiation reflected to space (it is bright). Thus, dust reduces the amount of solar radiation reaching the surface, reducing surface temperature. Dust can remain in the atmosphere for weeks and influence weather and climate over large regions. From NASA Earth Observatory.

Dust Storms Disrupt Day-to-Day Living

The high levels of dust in storms keep people indoors and damages internal combustion engines. Storms shut down airports, down power lines, and curtail other activity.

A haboob (dust storm) rolls in from the Gila River Indian reservation northward towards the south side of South Mountain in Phoenix, Arizona. The Wind Erosion Multimedia Archive has many photos of dust storms. From Clayton Esterson.

They [dust storms] disrupt traffic, coat our cars with a veil of desert dirt, deposit leaves and branches into our swimming pools and blow empty trash barrels around in the streets ... If we're at home, we usually have to run out to the back yard and rescue the patio chairs from certain doom: Blowing into our swimming pool. Blinking back the dirt from our eyes and attempting to ignore the grittiness in our teeth, we rush to make sure anything that isn't nailed down is either brought inside or tethered. Potted plants overturn, hummingbird feeders whip in the wind and I've even seen the patio umbrellas take off from neighbors' back yards like kites. From Desert Drivel Blog

Four people died and 42 others were injured in a series of chain-reaction interstate highway accidents during a blinding dust storm, authorities said. From Public Health Applications in Remote Sensing.

Dust Storms Erode Soil

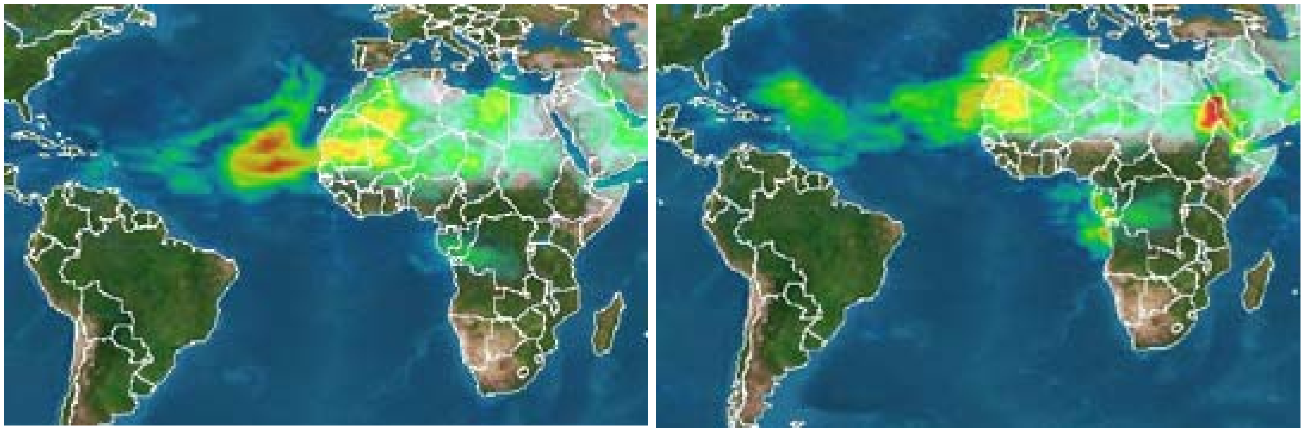
Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clays, and silts. Thus it removes the most fertile part of the soil and lowers soil productivity. Lyles estimated that top soil loss from wind erosion causes annual yield reductions of 339,000 bushels of wheat and 543,000 bushels of grain sorghum on 0.5 million hectares (1.2 million acres) of sandy soils in southwestern Kansas. From Wind Erosion Research Unit

Wind ero-

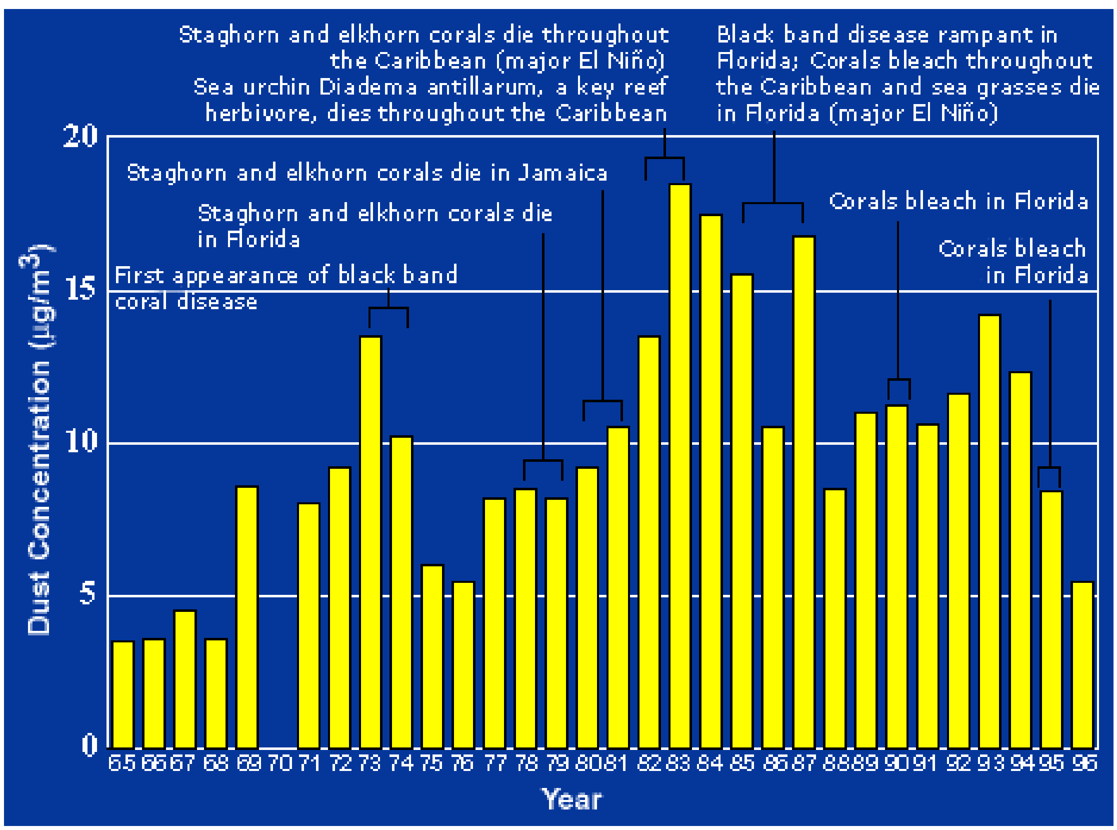
sion at Grand Forks County, North Dakota; 1 mile east, 1 1/2 mile north Larimore, North Dakota photographed on 11 may 1955. The condition of these fields was brought about by high velocity winds up to 89 mph as recorded at Grand Forks, North Dakota (5 miles away). The fence corner picture showing one woven wire fence on top of another indicates that wind erosion has occurred on these fields before. Excessive grazing by sheep has exposed some areas of the pasture to wind erosion. From Natural Resources Conservation Service, Wind & Water Erosion Pictures.

Dust Storms Carry Bacteria To Distant Places

Sahara dust storms carry heavy metals, bacteria, and other pathogens to the Caribbean, causing coral death.

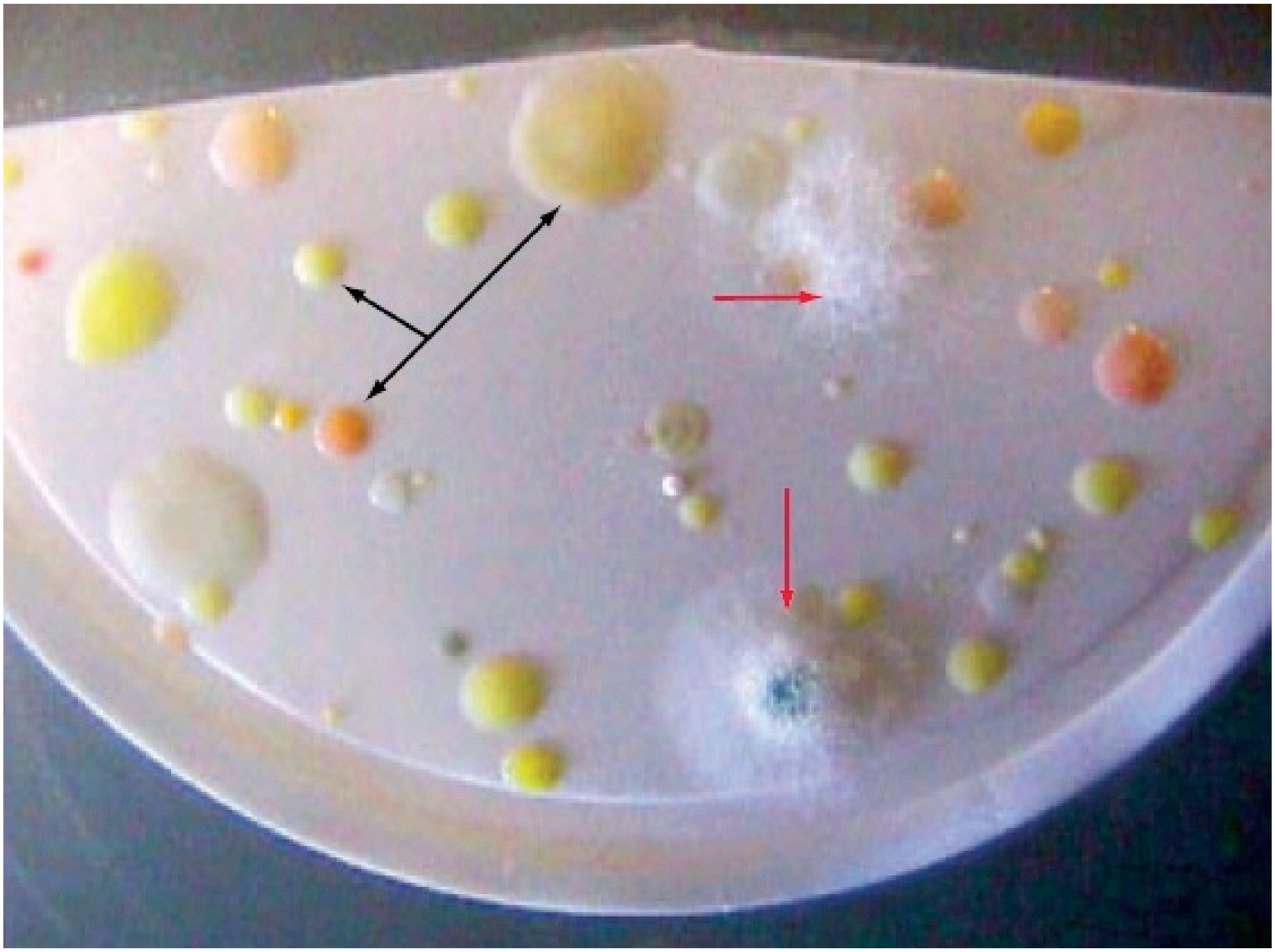


These two images from NASA's Total Ozone Mapping Spectrometer (TOMS) instrument show dust blowing off the Sahara in Africa and crossing the tropical Atlantic. The Total Ozone Mapping Spectrometer instrument aboard the Earthprobe TOMS satellite, captured these images of the dust event on June 17, 1999 (Left) as dust leaves Africa, and on July 2, 1999 (Right) as the dust approaches North America. From Laboratory for Atmospheres TOMS Project, NASA Goddard Space Flight Center, as reported in Dust Deals Droughts, Deluges by Forum für Wissenschaft, Industrie und Wirtschaft, reporting on work by Natalie Mahowald and Lisa Kiehl.



Dust concentrations in the air at Barbados in the Caribbean and onset of clral disease in Barbados waters. The increasing drought in the Sahel, beginning in the early 1970 and continuing to 2000 or later, has led to an increase in Saharan dust in the air over the Caribbean, an increase in pathogens in the air, at the same time coral diseases started to increase. Dr. Joe Prospero, University of Miami as discussed on US Geological Survey web site on Coral Mortality and

African Dust.



This half of an air filter represents 40 liters of air (roughly the amount it would take to fill a 10 gallon aquarium) sampled during a dust storm in Mali, Africa. The filter is placed on nutrient media for 48 hours so the viable microbes can grow. The shiny, colorful circles (indicated by the black arrows) are bacterial colonies. The fuzzy patches (indicated by the red arrows) are fungi. From U.S. Geological Survey Open-File Report 03–028, January 2003 African Dust Carries Microbes Across the Ocean: Are They Affecting Human and Ecosystem Health? a 396-KB pdf file.

Work by the U.S. Geological Survey finds that:

1. As of August 2005, preliminary identification has been made of >300 kinds of microorganisms cultured from air samples collected on St. Croix, St. John and Trinidad during dust and non-dust conditions. Air samples collected during dust events in the USVI and Trinidad contain approximately 2-3 times as many culturable microorganisms per volume as do air samples collected during non-dust conditions. Of those microorganisms identified to date, 25% are known plant pathogens and 10% are known opportunistic pathogens of humans. (Griffin, Ramsubhag, Smith, Gray in preparation; publication - Griffin et al. 2001, 2003)
2. Air in Mali contains orders of magnitude more microorganisms per volume than air sampled in the downwind areas (USVI and Trinidad) and more species. Of the hundreds of microorganisms cultured and isolated from Sahara and Sahel (Mali, West Africa) air samples, DNA sequencing has been used

to identify 50 types of bacteria (and 3 genera of fungi) and preliminary identifications have been made on >100 additional kinds of bacteria. Of the culturable bacteria identified thus far, 10% are known animal pathogens, 5% are plant pathogens, and 27% are opportunistic human pathogens. (Kellogg, Smith, Coulibaly, Gray in preparation; publication - Kellogg et al., 2004)

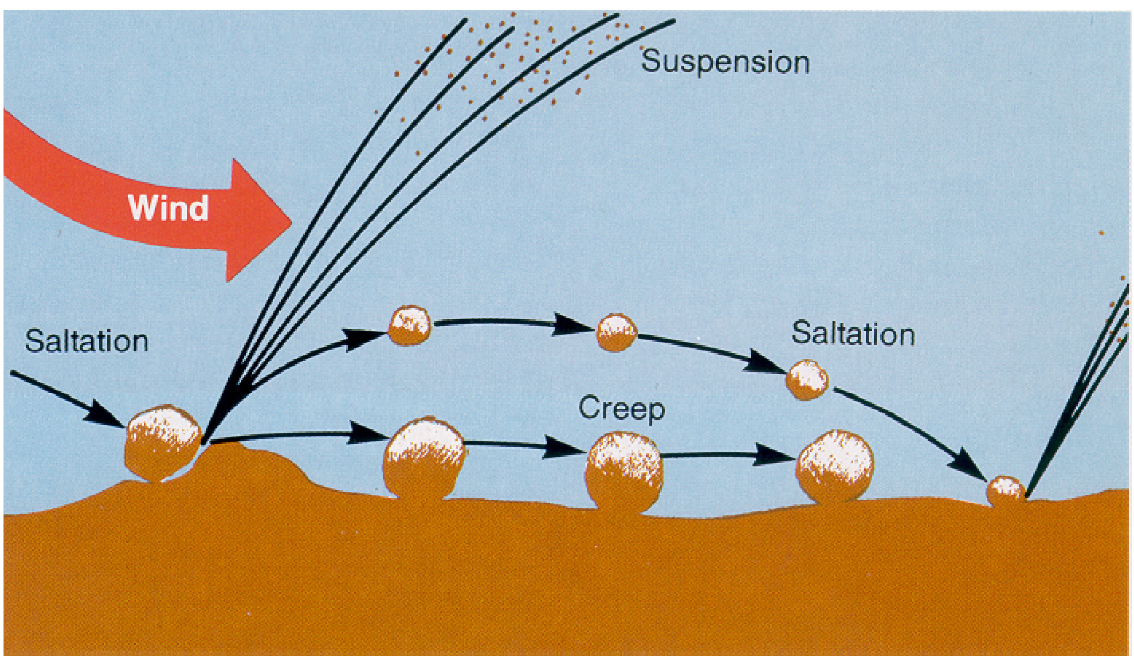
3. A pilot study found that dust collected in the USVI during African dust conditions was highly toxic to gametes and embryos of some marine organisms (Nipper, Carr, Garrison in preparation). From Coral Mortality and African Dust: Summary of Findings.

Dust Fertilizes The Oceans

In the chapter on Carbon Cycle, The Ocean, and the Iron Hypothesis we learned that many large oceanic areas do not have enough dissolved iron necessary to support large populations of phytoplankton. Dust carries iron from the land to the open ocean, supplying needed iron, leading to phytoplankton blooms covering large areas of the North Atlantic and Caribbean.

Causes of Blowing Dust

As wind speed increases over soil with no vegetation, small sand particles (0.1–0.5 mm in diameter) begin to move. At first, particles on the surface creep forward. As wind speed continues to increase, small particles fly through the air for a few centimeters before falling back to the surface. This is called saltation. When the saltating particles hit the ground, they may dislodge other particles, especially smaller particles. Finally, if the wind speed is high enough, small particles become suspended in the air. Suspended particles are carried high into the air where they become the dust of a dust storm.



Creep, saltation, and suspension of particles by wind. From Wind Erosion Research Unit, Wind Erosion Simulation Models.

Factors Influencing Wind Erosion

Wind erosion is influenced by many factors:

1. Vegetation. Vegetation slows the wind at the soil level, retarding erosion. Roots bind the soil, further retarding erosion. Lack of vegetation (ground cover) enhances wind erosion. Windbreaks of trees and shrubs reduce wind speed near the ground. Small changes in vegetation lead to large changes in erosion by the wind. If the vegetation covers more than 20% of
2. Soil moisture. Surface tension by water in moist soil exceeds the wind force on surface particle. Wind cannot erode moist soil. Soil with a moisture content of only 1% is very difficult to erode.
3. Structure of the surface. Organic material, iron, and free aluminum at the surface reduces erosion. Sodium or salt at the surface leads to dust at the surface, enhancing erosion.
4. State of the soil surface. Desert pavement, a layer of pebbles covering the surface, plus desert varnish on the pebbles, a thin layer of clay with iron and manganese oxides produced by bacteria at the surface, strongly inhibits erosion. Driving on the surface destroys the protection leading to rapid erosion.
5. Climate. Erosion requires arid climate in regions with strong winds.

12.5 Case Study: Desertification in The Sahel

You have read about land degradation and that:

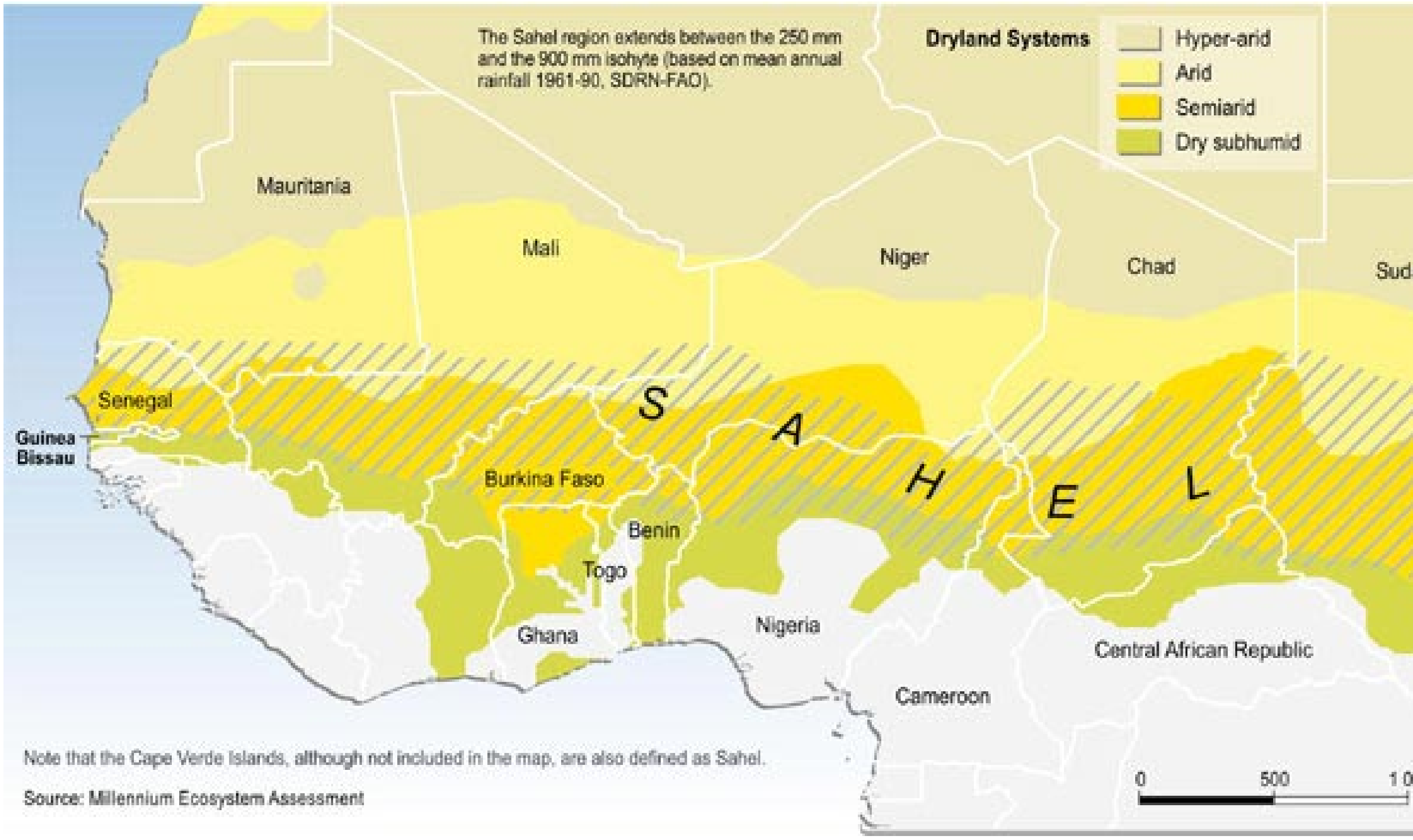
> Desertification is the degradation of land in arid, semi-arid, and dry sub-humid areas. It is caused primarily by human activities and climatic variations. Desertification does not refer to the expansion of existing deserts. It occurs because dryland ecosystems, which cover over one third of the world's land area, are extremely vulnerable to over-exploitation and inappropriate land use. Poverty, political instability, deforestation, overgrazing, and bad irrigation practices can all undermine the land's fertility. From Food and Agricultural Organization web page on Desertification.

You also read that both nature and humans influence desertification. Here we look at one region that has captured the attention of the world for at least the past 40 years— the Sahel of north Africa. Beginning in the 1960s, the area became very dry and hundreds of thousands died of starvation. Was the devastation the result of human misuse of the land, was it the result of natural changes in climate, or was it the result of both? Answers to these questions have not come easily. At first, land use and land degradation were thought to be the primary causes. The United Nations Conference on Desertification focused attention on land use, and led to the emphasis on land degradation as the cause of desertification. Since then, we have found that the issue is more complicated.

What is the Sahel?

The Sahel is the semi-arid transition region between the Sahara desert to the north and wetter regions of equatorial Africa to the south. It extends from the Atlantic in the west to the Indian ocean in the east. It has high variability of rainfall, and the land consists of stabilized ancient sand seas. It is one of the poorest and most environmentally degraded areas on earth.

Near Wolof village of Ndiagene in Senegal in the Sahel. From Ewan Robinson Rural Visit as shown in NASA Earth Observatory article on Desertification.



Map of the sahel in north Africa. Some scientists include Eritrea in the sahel. From Millennium Ecosystem Assessment report onEcosystems and Human Well-Being Desertification Synthesis.

History of Desertification in Sahara and Sahel

Climate of the Sahel and the Sahara has changed greatly over the past 11,000 years since the end of the last ice age. The Sahara has expanded and contracted, changing the course of civilizations.

One of the most striking climate changes of the past 11,000 years caused the abrupt desertifi-

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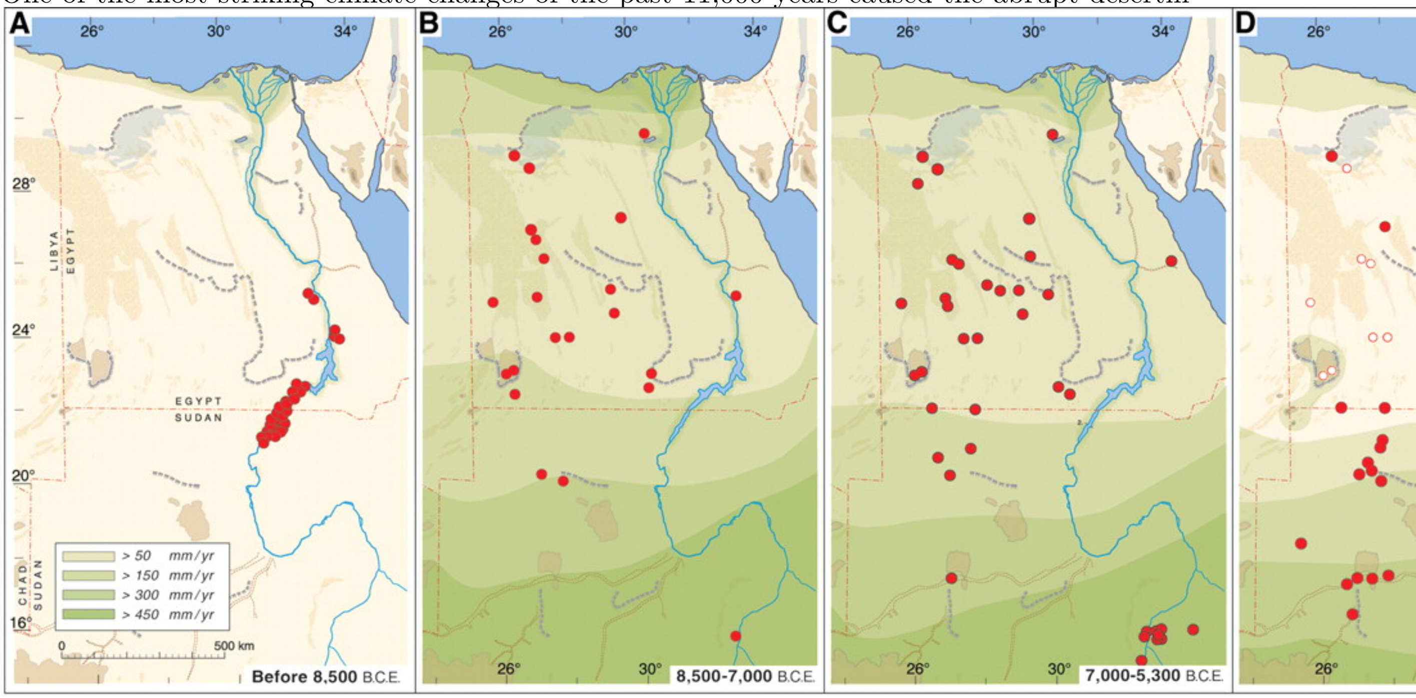
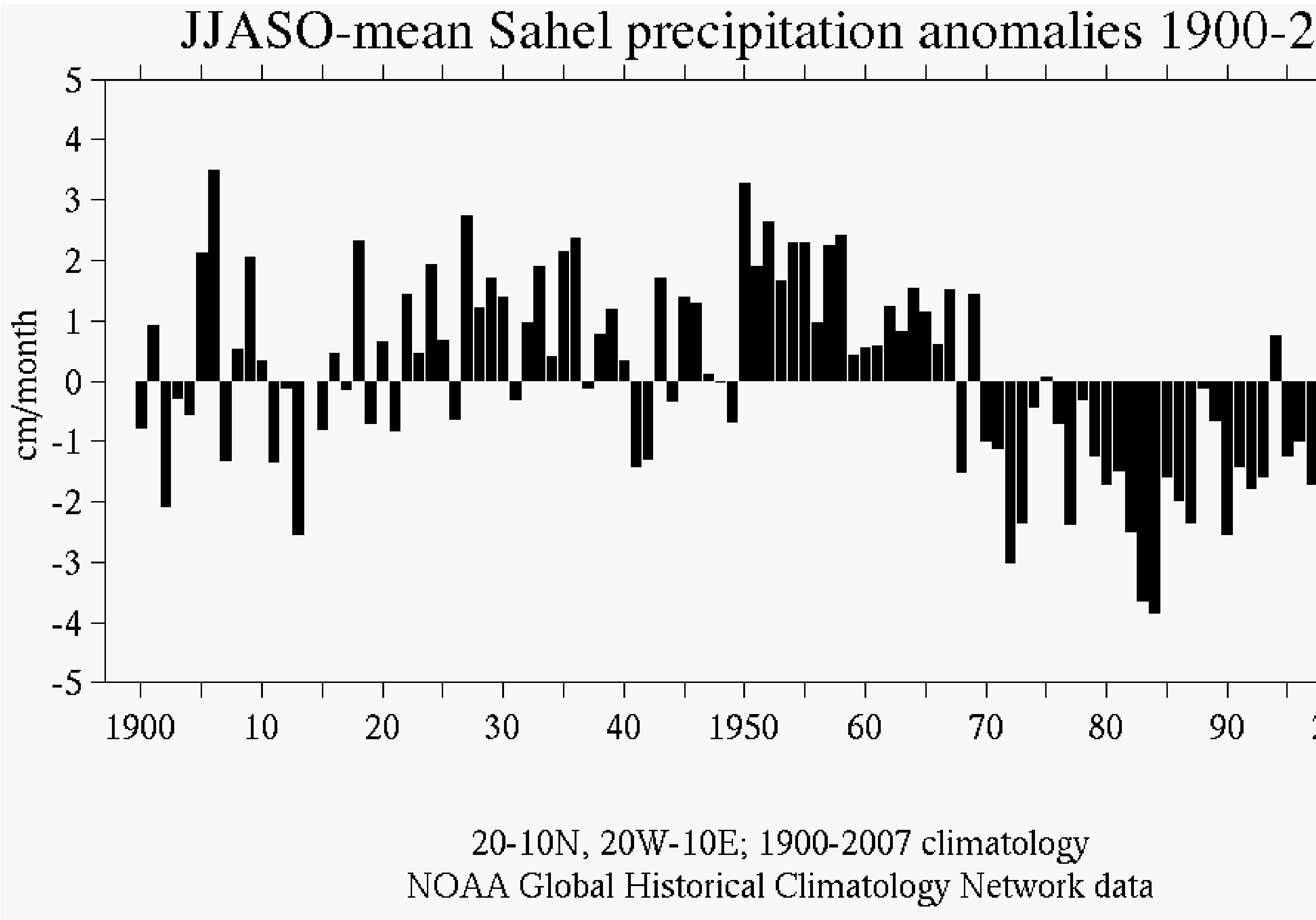


Climate-controlled occupation in the Eastern Sahara during the main phases of the Holocene. Red dots indicate major occupation areas; white dots indicate isolated settlements in ecological refuges and episodic transhumance. Rainfall zones are delimited by best estimate isohyets on the basis of geological, archaeozoological, and archaeobotanical data. (A) During the Last Glacial Maximum and the terminal Pleistocene (20,000 to 8500 BC), the Saharan desert was void of any settlement outside of the Nile valley and extended about 400 km farther south than it does today. (B) With the abrupt arrival of monsoon rains at 8500 BC, the hyper-arid desert was replaced by savannah-like environments and swiftly inhabited by prehistoric settlers. During the early Holocene humid optimum, the southern Sahara and the Nile valley apparently were too moist and hazardous for appreciable human occupation. (C) After 7000 BC, human settlement became well established all over the Eastern Sahara, fostering the development of cattle pastoralism. (D) Retreating monsoon rains caused the onset of desiccation of the Egyptian Sahara at 5300 BC Prehistoric populations were forced to the Nile valley or ecological refuges and forced to exodus into the Sudanese Sahara where rainfall and surface water were still sufficient. The return of full desert conditions all over Egypt at about 3500 BC coincided with the initial stages of pharaonic civilization in the Nile valley. Click on the image for a zoom. From Kuper and Kröpelin (2006).

Since 3,000 BC the Sahel has had periods of more rain followed by periods of drought at intervals of 1,500 ± 500 years. The more recent changes are tied to changes in north Atlantic ocean temperatures.

Recent Climate Change and Rainfall

Years of above average rainfall from the 1950s to the 1970s, were followed by drought in the sahel starting in the late 1960s. The drought has had a devastating impact on this ecologically vulnerable region and was a major impetus in the establishment of the United Nations Convention on Combating Desertification and Drought. Since then, meteorologists, oceanographers, and geographers have sought to understand what caused the drought.

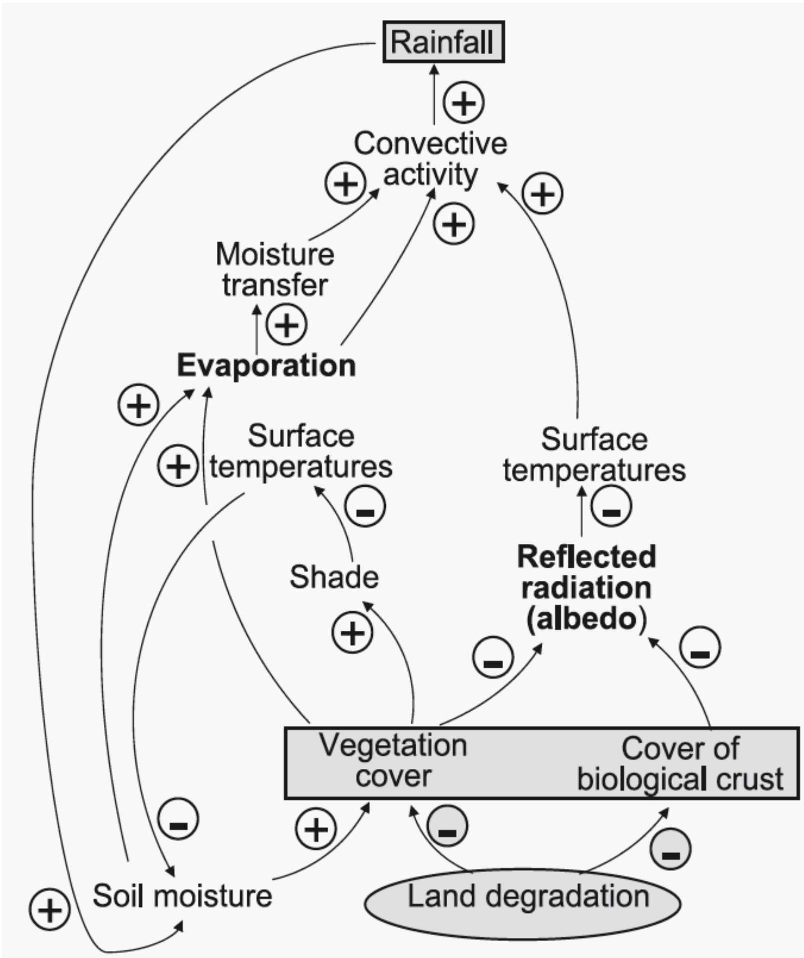


Sahel rainfall from 1900 to 2007 averaged over June, July, August, September, and October JJASO. Click on image for a zoom. From Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Sahel Rainfall Index.

Recent work by meteorologists and oceanographers has shown that much of the recent year-to-year changes in Sahel rainfall are forced by changes in sea-surface temperature in the Gulf of Guinea (on the equator near the prime meridian) and by El Niño in the Pacific. When the gulf is warm, the Intertropical Convergence Zone shifts south away from the Sahel reducing the African monsoon that draws moist air into the Sahel. Longer term changes in rainfall from decade to decade are forced by changes in sea-surface temperature in the western Indian and tropical Atlantic oceans. When these areas are cool, Sahel rainfall increases.

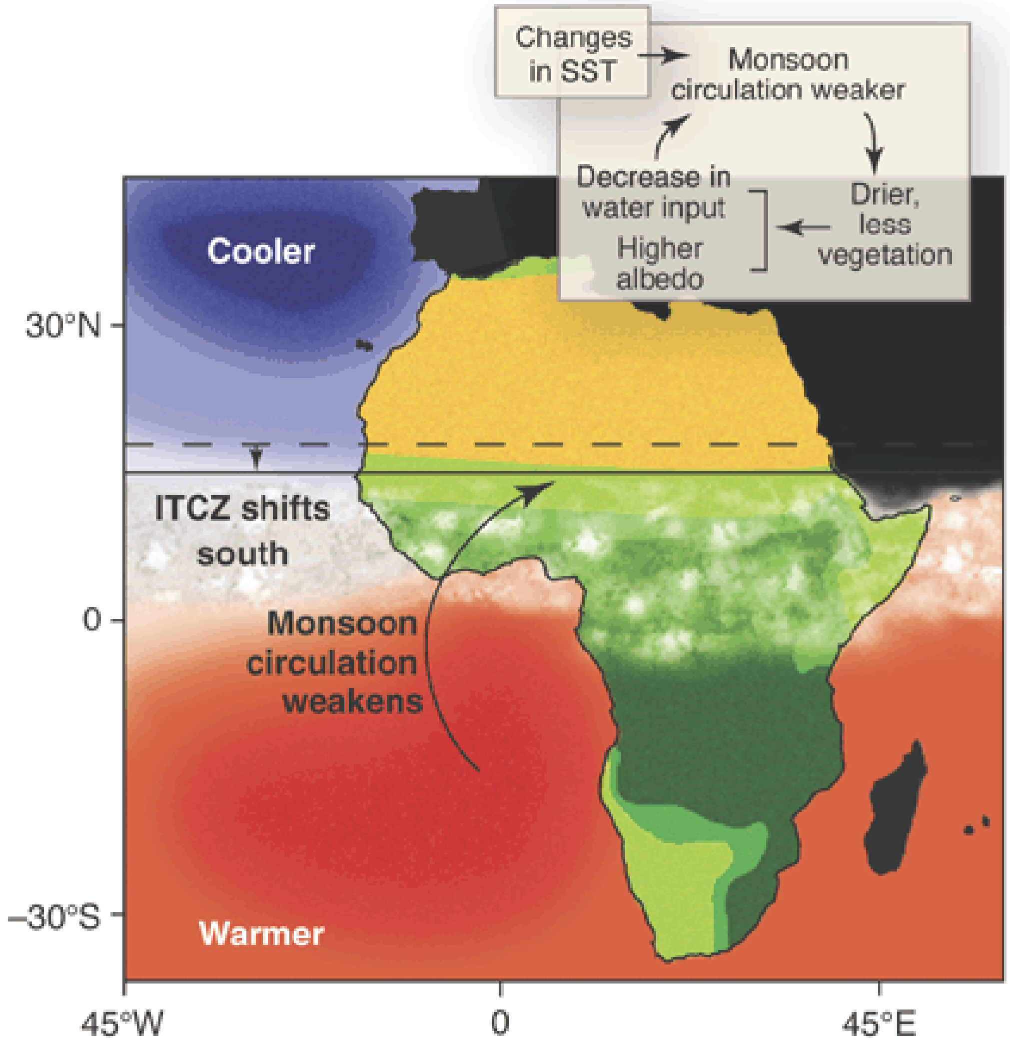
The oceanic forcing of Sahel rainfall is amplified by land-atmosphere feedbacks. As the land dries out, there is less vegetation, less evaporation from the land, and more sunlight is reflected from the land. These processes further weaken the monsoon. This positive feedback also involves land degradation due to human interactions with the land.

Land-atmosphere feedbacks



amplifying climate change in the Sahel. Click on image for a zoom. From Dryland Systems in Ecosystems and Human Well-Being: Current State and Trends, part of the Millennium Assessment.

Rains return when the gulf is cooler, and rainfall shifts north watering the Sahel. Evaporation from the land increases, less sunlight is reflected, and the African monsoon strengthens.



Sahel rainfall are forced by changes in sea-surface temperature in the Gulf of Guinea. The response is amplified by land-atmosphere feedbacks in the Sahel. From Zeng (2003).

Human Dimensions of Sahel Land Degradation

The drying of the Sahel in the late 20th century caused widespread famine that attracted world-wide attention, including the United Nations Conference on Desertification (UNCOD) in Nairobi, Kenya in 1977, the 1993 Convention to Combat Desertification, the 2006 International Year of the Desert and Desertification, and the Millennium Ecosystem Assessment.

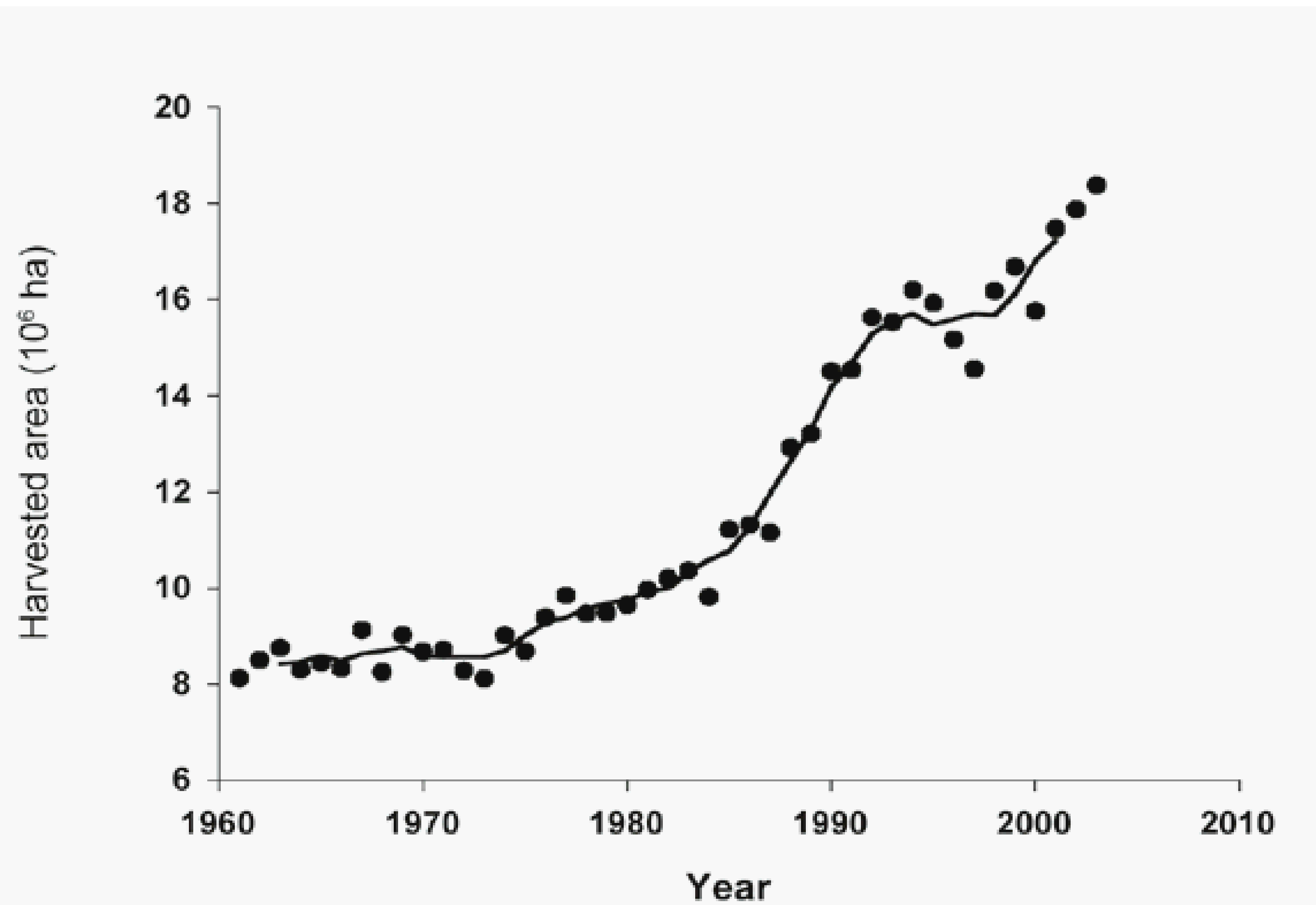
The studies show that climate change strongly influences the Sahel in recent decades, but it is only part of the story:

> Rainfall variability is a major driver of vulnerability in the Sahel. However, blaming the 'environmental crisis' on low and irregular annual rainfall alone would amount to a sheer oversimplification and misunderstanding of the Sahelian dynamics. Climate is nothing but one element in a complex combination of processes that has made agriculture and livestock farming highly unproductive. Over the last half century, the combined effects of population growth, land degradation (deforestation, continuous cropping and overgrazing), reduced and

erratic rainfall, lack of coherent environmental policies and misplaced development priorities, have contributed to transform a large proportion of the Sahel into barren land, resulting in the deterioration of the soil and water resources. From From United Nations Environmental Programme, World Agroforestry Center. Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector.

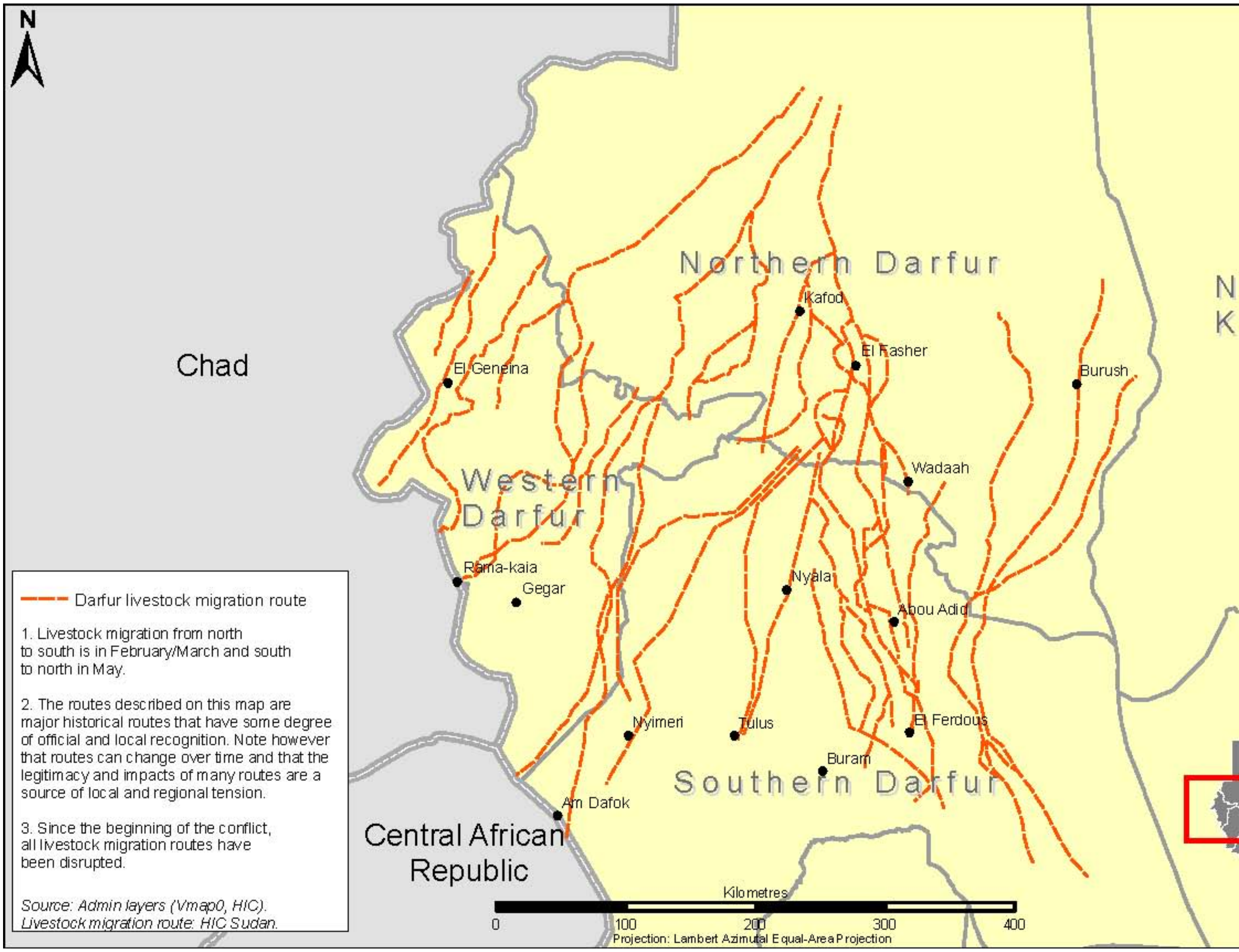
The human influences include:

1. **Population increase.** Population is doubling every 20 years. The growth rate of population (3% per year) exceeds the growth rate of food production (2% per year). The total population is around 260,000,000 people.
2. **Poverty.** Per capita income varies from \$500/year in Burkina Faso to \$1,000/year in Mali to \$2,000/year in Nigeria. In contrast, the per capita income in France, German, and the UK is about \$35,000/year. All are estimates for 2007. The area includes three of the four poorest countries on earth.
3. **Over grazing, poor farming methods, and use of trees and vegetation for firewood.** Overgrazing and poor agricultural practices lead to soil erosion, further degrading the land. The traditional Parkland system (integrated crop-tree-livestock systems), which is the predominant land use system and the main provider of food, nutrition, income, and environmental services, is rapidly degrading—woody biodiversity and cover is being lost, and soil fertility is declining from already low levels through exhaustive cropping practices and soil erosion. From West Africa Drylands Project.

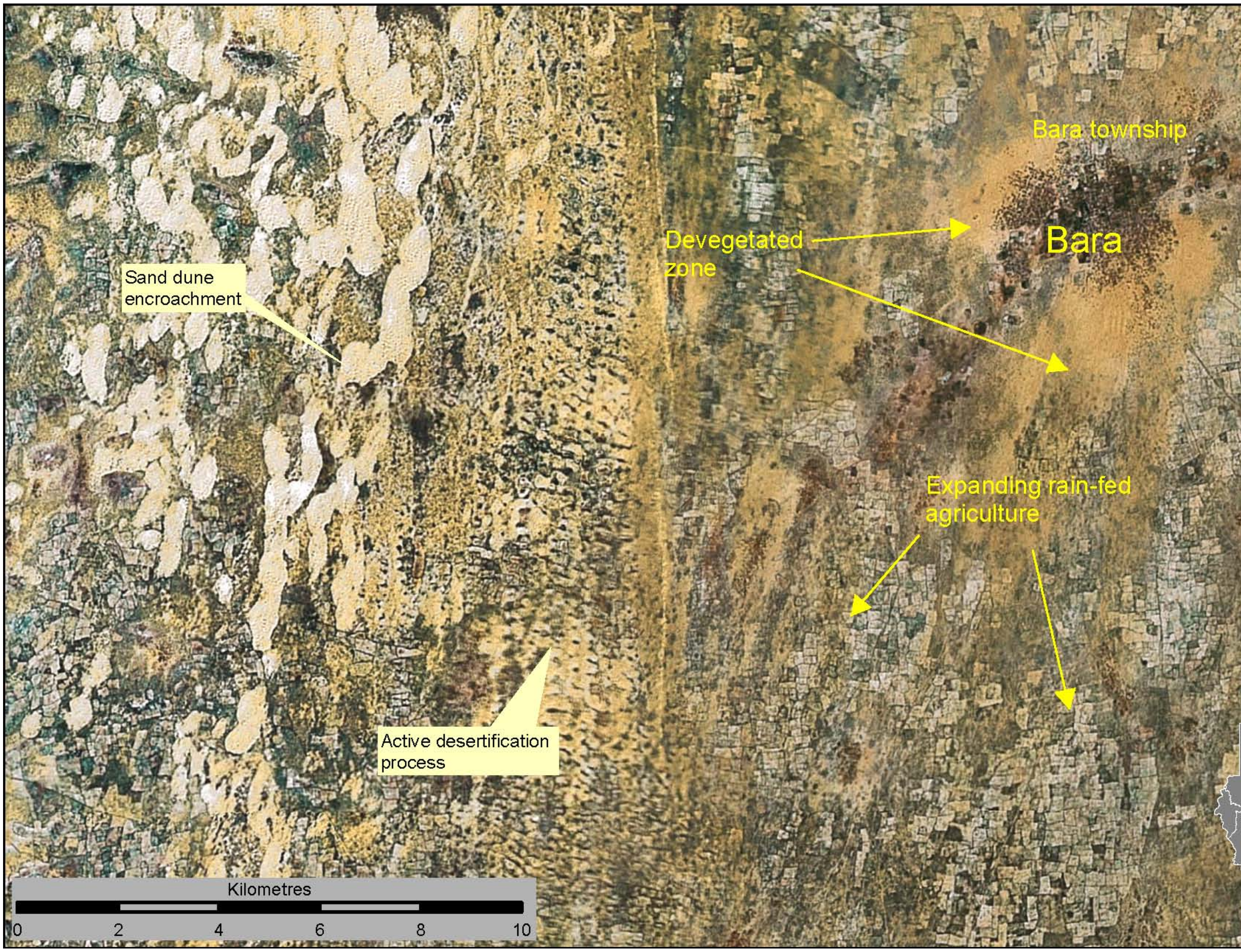


Area devoted to crops in the Sahel since 1960. The need to grow more crops, both for export and for local use, has led to expansion of agriculture into areas poorly suited for crops, leading to land degradation in dry years. From United Nations Environmental Programme, World Agroforestry Center. Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector.

4. **Colonial Influence.** The Sahel was divided into countries by European nations. The boarders were set by political processes that mostly ignored the local people and their use of the land. The new countries began to enforce boundaries limiting the ability of nomads to move their herds in response to changing rain, from dry to wet areas. As a result, nomads were forced into villages, and in dry years their herds overgrazed the area around villages and cities.



Major historical migration routes used by nomadic herders in the past. Now the borders with Chad and the Central African Republic are closed, and even borders between provinces in the Sudan are closed, and herders must stay within their own province. The closing of the borders causes environmental and political problems. Click on the map for a zoom. From United Nations Environmental Program.



Desertification in Bara, Sudan due to restrictions on movement of herds of animals. Notice the devegetated areas around Bara. Click on the image for a zoom. From United Nations Environmental Programme Natural Disasters and Desertification (a 0.6 MByte pdf file).

Cattle concentrated around a waterhole near Bamako, Mali, Africa. Click on image for a zoom. From Manfred Schweda.

5. **Migration due to political instability and war.** Conflicts in Niger, Nigeria, Mali, Darfur, and Eritrea have caused mass migration of people from rural areas to refugee camps to nearby countries.

The end result of land degradation.

Completely degraded land in northern Darfur, just outside a large refugee camp. From United Nations Environmental Programme Natural Disasters and Desertification (a 0.6 MByte pdf file).

12.6 End of Chapter Review & Resources

Chapter Summary

We use natural resources for many things. Natural resources give us food, water, recreation, energy, building materials, and luxury items. Many resources vary in their availability throughout the world. Some are rare, difficult to get or in short supply. We need to conserve our natural resources, protecting them from pollution and overuse. We can use materials less or recycle to conserve resources. We can also make efforts to reduce pollution and soil erosion in order to conserve resources.

Review Questions

1. List five general things we get from natural resources.
2. We depend on forests as habitat for wildlife. How does this make a forest an important resource for people?
3. How could human life be affected if a large amount of soil erosion affected our soil resources?
4. How does discarding products lead to more resource use?
5. How does choosing to walk or ride a bicycle instead of riding in a car help conserve resources?
6. What is desertification?
7. What causes desertification?
8. How can we stop desertification?
9. What are different land uses by humans?
10. What are renewable energy and natural resources?
11. What are non-renewable energy and natural resources?
12. Which is more sustainable: using renewable resources or nonrenewable resources?

Vocabulary

- renewable - A resource that can be regenerated, new ones can be made or grown to replace ones that get used.
- nutrients - Substances that a living thing needs to grow.
- timber - Trees that are cut for wood to be used for building or some other purpose.
- non-renewable - A resource that cannot be regenerated; once it is used up, it cannot be replaced within a human lifetime.
- import - To receive from another country.
- export - To send out to another country.
- conserve - To keep things safe and ensure that they will always be around.

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Reynolds, J. F., D. M. S. Smith, et al. (2007). "Global Desertification: Building a Science for Dryland Development." Science 316(5826): 847-851.

Abstract: In this millennium, global drylands face a myriad of problems that present tough research, management, and policy challenges. Recent advances in dryland development, however, together with the integrative approaches of global change and sustainability science, suggest that concerns about land degradation, poverty, safeguarding biodiversity, and protecting the culture of 2.5 billion people can be confronted with renewed optimism. We review recent lessons about the functioning of dryland ecosystems and the livelihood systems of their human residents and introduce a new synthetic framework, the Drylands Development Paradigm (DDP). The DDP, supported by a growing and well-documented set of tools for policy and management action, helps navigate the inherent complexity of desertification and dryland development, identifying and synthesizing those factors important to research, management, and policy communities.

White, Robin P, and Janet Nackoney (2003) Drylands, People, and Ecosystem Goods and Services: A Web-Based Geospatial Analysis. World Resources Institute Report.

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Kandji, Serigne Tacko; Verchot, Louis; and Mackensen, Jens. 2006. Climate Change and Variability in the Sahel Region: Impacts and Adaptation Strategies in the Agricultural Sector. United Nations Environmental Programme and World Agroforestry Centre.

Giannini, A., R. Saravanan, and Chang. (2003). Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. Science 302 (5647): 1027–1030. We present evidence, based on an ensemble of integrations with NSIPP1 (version 1 of the atmospheric general circulation model developed at NASA's Goddard Space Flight Center in the framework of the Seasonal-to-Interannual Prediction Project) forced only by the observed record of sea surface temperature from 1930 to 2000, to suggest that variability of rainfall in the Sahel results from the response of the African summer monsoon to oceanic forcing, amplified by land-atmosphere interaction. The recent drying trend in the semiarid Sahel is attributed to warmer-than-average low-latitude waters around Africa, which, by favoring the establishment of deep convection over the ocean, weaken the continental convergence associated with the monsoon and engender widespread drought from Senegal to Ethiopia.

Reynolds, J. F., D. M. S. Smith, et al. (2007). Global Desertification: Building a Science for Dryland Development. Science 316 (5826): 847–851. In this millennium, global drylands face a myriad of problems that present tough research, management, and policy challenges. Recent advances in dryland development, however, together with the integrative approaches of global change and sustainability science, suggest that concerns about land degradation, poverty, safeguarding biodiversity, and protecting the culture of 2.5 billion people can be confronted with renewed optimism. We review recent lessons about the functioning of dryland ecosystems and the livelihood systems of their human residents and introduce a new synthetic framework, the Drylands Development Paradigm (DDP). The DDP, supported by a growing and well-documented set of tools for policy and management action, helps navigate the inherent complexity of desertification and dryland development, identifying and synthesizing those factors important to research, management, and policy communities.

Zeng, N. (2003). ATMOSPHERIC SCIENCE: Drought in the Sahel. Science 302 (5647): 999-1000.

Chapter 13

Energy Use & Natural Resources

13.1 Introduction

Humans require natural resources to survive, and those resources are based on ecosystem services. There are both renewable and non-renewable resources. Sustainabily using energy sources allows both current and future generations the chance to a good life.

Chapter Objectives

- Describe the primary renewable energy sources and the economic and natural barriers to their widespread use.
- Compare the social and environmental impacts of the generation and use of solar, wind, hydroelectric, biomass, and geothermal energy.
- Discuss the causes and consequences of the tendency for nations to move from renewable to non-renewable fuels as they develop.
- Distinguish between renewable and non-renewable energy sources.
- Outline the formation and recovery of fossil fuels and their current and future roles in U.S. energy supply.
- Describe the consequences of extracting and burning coal, natural gas, and oil.
- Evaluate the benefits and costs of nuclear power.
- Describe how human activities including technology affect ecosystem services.

13.2 Our Natural Resources

While natural resources would include water and biodiversity, those two important topics are covered in separate chapters.

Defining **natural resources** raises important philosophical questions.

Resources are useful or valuable. But are resources useful for and valuable to humans – or all life? If we "use" them, do we necessarily "consume" them? Is value limited to economics? Are resources limited to materials, or can they include processes, systems, and living things?

Definitions of "natural" go straight to the heart of our views about ourselves. Most definitions include a tension or conflict between the human and the non-human parts of the Earth: Anything that is natural is "not altered or disguised," "not produced or changed artificially," or, rather unhelpfully, "found in nature." We often define nature as separate from humans: "the world of living things and the outdoors" or with elements of inner conflict ("a primitive state of existence, untouched and uninfluenced by civilization or artificiality") or even religion ("humankind's natural state as distinguished from the state of grace").

It is not an idle exercise to think carefully about your own definition of natural resources, because such thinking can clarify your relationship and responsibilities to the Earth. Do natural resources exist only for humans to use (or exploit – a term repeated in many definitions)? Are we apart from nature, or a part of nature? In what ways are we similar to other species? How are we different? How do those similarities and differences help us to define our responsibilities to "nature" – to other species and our physical environment?

Historically, the concept of natural resources was intended as a measure of respect and appreciation for the materials Earth provided, and the supplies humans used and modified to develop the civilization in which they lived. Economic value was primary, and a list of natural resources would include energy sources such as coal or oil and raw materials such as iron or copper. Living things could be, but often were not added: fibers from plants, and skins from animals.

As use became exploitation and later depletion, we began to better appreciate our dependence on natural resources, as well as our power over them. Economist E.F. Schumacher, in a 1973 series of essays titled *Small is Beautiful,* suggested that our economy is unsustainable because natural resources (especially energy) can be depleted. He made the case that natural resources should be considered capital, rather than expendable – *conserved,* rather than simply *used.* He also argued that nature's capacity to resist pollution is limited, pointing to the value of whole ecosystems and ecosystem services. During the 1990s, ecological economist Robert Constanza calculated that "nature's services" were worth $33 trillion per year – more than the $25 trillion total of the inter-human economy at that time. Although awareness of resource depletion and ecosystem services is increasing, their values remain inadequately recognized by our economy, and sustainability remains a goal for the future.

What definition for natural resources shall we use? On the Department of Energy's "Ask a Scientist" website, Bob Hartwell defines a natural resource as "something supplied by nature which supports life on this planet." This concise description includes most of the ideas we've discussed above, and views human use with an ecological perspective appropriate for the study of biology. Humankind is a part of nature, one species in an interdependent web which includes the Earth and all life. Without question, we are a unique species: we have the power to change that interdependent web in ways no other species can, we have the ability to learn about and understand the patterns and processes which maintain the web, and we have the responsibility to use our natural resources together with that understanding in ways which sustain the web – for our ourselves and for all life.

13.3 Renewable vs. Non-renewable Resources

Natural resources may be classified as renewable or non-renewable. Renewable resources are those that can be regenerated, which means new materials can be made or grown again at the same rate as they are being used. For example, trees are a renewable resource because new trees can be grown to replace trees that are cut down for use. Other examples of renewable resources include soil, wildlife, and water. However, some resources, like soil, have very slow rates of renewal, so we still need to conserve them. It is also important to realize that while these resources are in most cases renewable, we can still pollute them, damage them or over-use them to the point that they are not fit for use anymore. Fish are considered a renewable resource because we can take some fish but leave others to reproduce and create new fish for later use. Imagine, however, what can happen if we over-fish, or take too many fish at one time. If we over-harvest our trees or wildlife resources, we may not leave enough to let the resource renew itself.

Non-renewable resources are resources that renew themselves at such slow rates that, practically, they cannot be regenerated. Once we use them up, they are gone for good—or at least for a very, very long time. Coal, oil, natural gas and minerals are non-renewable resources. It takes millions of years for these materials to form, so if we use them to the point of depletion, new resources will not be made for millions more years. We can run out of these resources.

Common Materials We Use From the Earth

What do a CD, a car, a book, a soda can, a bowl of cereal, and the electricity in your home all have in common? They are all made using natural resources. For example, a CD and a soda can are made of metals that we mine from the Earth. A bowl of cereal comes from wheat, corn, or rice that we grow in the soil. The milk on the cereal comes from cows that graze on fields of grass. We depend on natural resources for just about everything that we eat and use to keep us alive, as well as the things that we use for recreation and luxury. In the United States, every person uses about 20,000 kilograms (40,000 pounds) of minerals every year for a wide range of products such as cell phones, TVs, jewelry, and cars. Table 20.1 shows some common objects, the materials they are made from and whether they are renewable or non-renewable.

Table 13.1: **Table 20.1: Objects and Their Required Resources**

Common Object	Natural Resources Used	Are These Resources Renewable or Non-renewable?
Cars	15 different metals, such as iron, lead, and chromium to make the body	Non-renewable
Jewelry	Precious metals like gold, silver, and platinum; gems like diamonds, rubies, emeralds, turquoise	Non-renewable
Electronic appliances (TVs, computers, DVD players, cell phones, etc.	Many different metals like copper, mercury, gold	Non-renewable
Clothing	Soil to grow fibers such as cotton; sunlight for the plants to grow; animals for the fur and leather	Renewable
Food	Soil to grow plants; wildlife and agricultural animals	Renewable

Table 13.1: (continued)

Bottled water	Water from streams or springs; petroleum products to make plastic bottles	Non-renewable and renewable
Fuel	Petroleum drilled from wells	Non-renewable
Household electricity	Coal, natural gas, solar power, wind power, hydroelectric power	Non-renewable and renewable
Paper	Trees, sunlight, soil	Renewable
Houses	Trees for timber; rocks and minerals for construction materials, for example; granite, gravel, sand	Non-renewable and renewable

Human Population and Resource Use

As the human population grows, so does the use of our natural resources. A growing population creates a demand for more food, more clothing, more houses and cars, etc. Population growth puts a strain on natural resources. For example, nearly 500 people move into the Tampa, Florida area every week (Figure 20.4). Tampa's population is growing quickly. The Tampa area may have over 3 million people by 2010. One of Tampa's rivers, the Hillsborough River, is pumped for drinking water to support all the people. Too much water is being taken from the river. The river is becoming salty, as water from the nearby Gulf of Mexico starts to take the place of the **freshwater** being pumped out. This hurts wildlife and may eventually make the river water unsuitable for human use. Many other examples like this are taking place worldwide.

Resource Availability

You can see from the table above that many of the resources we depend on are non-renewable. We will not be able to keep taking them from the Earth forever. Also, non-renewable resources vary in their availability. Some are very abundant and others are rare. Precious gems, like diamonds and rubies, are valuable in part because they are so rare. They are found only in small areas of the world. Other materials, like gravel or sand are easily located and used. Whether a resource is rare or abundant, what really determines its value is how easy it is to get to it and take it from the Earth. If a resource is buried too deep in the Earth or is somehow too difficult to get, then we don't use it as much. For example, the oceans are filled with an abundant supply of water, but it is too salty for drinking and it is difficult to get the salt out, so we do not use it for most of our water needs.

Resource availability also varies greatly among different countries of the world. For example, 11 countries (Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela) have nearly 80% of all the world's oil (Figure 20.5). However, none of these is the world's biggest user of oil. In fact, the biggest users of oil, the United States, China, and Japan, are all located outside this oil-rich region. This difference in availability and use of resources can be a source of economic and political trouble throughout the world. Nations that have abundant resources often **export** them to other countries, while countries that lack a resource must **import** it from somewhere else.

In developed countries like the United States and most of Europe, we often use many more natural resources than we need just to live. We have many luxury and recreational materials made from resources. We also tend to throw things away quickly because we can afford to replace them. Discarding materials not only leads to more resource use, but it also leads to more waste that has to be disposed of in some way. Pollution from discarded materials degrades the land, air, and water (Figure 20.6). As our cities and neighborhoods grow, we use more and more resources and produce more and more waste. Natural resource use is generally lower in developing countries because people cannot afford to use as much. Still, developing countries need to actively protect their resources by adopting sustainable practices as they develop.

Conserving Natural Resources

We need to conserve natural resources so that we can continue to use them in the future, and so that they will be safe for use. While renewable resources will not run out, they can become degraded or polluted. For example, water is a renewable resource, but we can pollute it to the point that it is not safe for use. Reducing use and recycling materials is a great way to conserve resources (Figure 20.7). Many people are also researching ways to find renewable alternatives to non-renewable resources. Here is a checklist of some things we can do to conserve resources:

- Purchase less stuff (use items as long as you can, ask yourself if you really need something new.)
- Reduce excess packaging (for example, drink water from the tap instead of buying it in plastic bottles).
- Recycle materials like metal cans, old cell phones, and plastic bottles.
- Purchase products made from recycled materials.
- Keep air and water clean by not polluting in the environment.
- Prevent soil erosion.
- Plant new trees to replace ones that we cut down.
- Drive cars less, take public transportation, bicycle, or walk.
- Conserve energy at home (for example, by turning out lights when they are not needed

Read about these energy sources from the US department of Energy website (click on all the links on the left hand column): http://www.energy.gov/energysources/bioenergy.htm

13.4 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 (**Figures ??**, 13.1). 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.

Table 13.2:

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

Figure 13.1: 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

Table 13.3:

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.

Table 13.4:

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_EnergySense-NewEngland/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.jpeg

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

13.5 Non-Renewable Resources

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

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

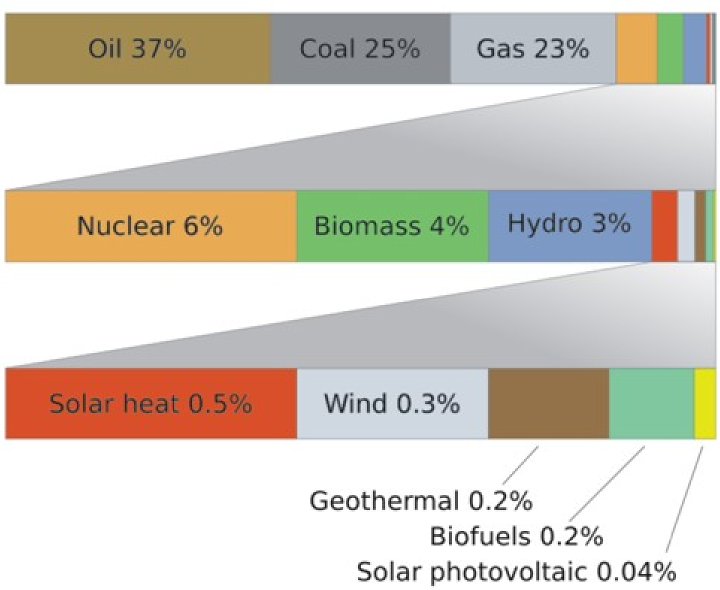


Figure 13.2: Global energy use includes mostly non-renewable (oil, coal, gas, and nuclear) but increasing amounts of renewable (biomass, hydro, solar, wind, geothermal, biofuels, and solar photovoltaic) resources.

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

Table 13.5:

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

Table 13.6:

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.

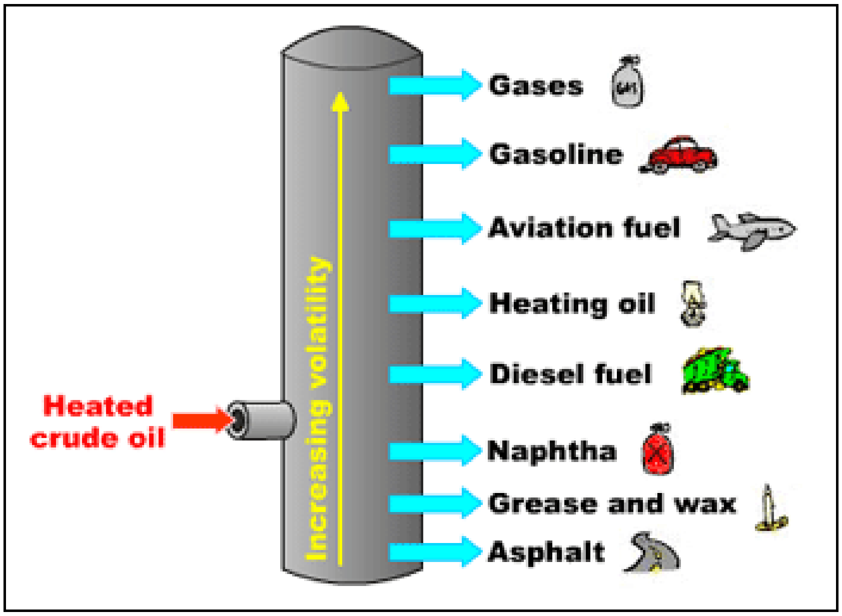
Oil recovery can involve more than one stage. The primary stage involves pumping oil from reservoirs under the normal reservoir pressure. About 25 percent of the oil in a reservoir can be removed during this stage. The secondary recovery stage involves injecting hot water into the reservoir around the 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)

Table 13.7:

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

Table 13.7: (continued)

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)

Table 13.8:

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.

PHOTO CREDIT: VAHE PEROOMIAN

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 490º 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.

13.6 Energy Use

How much energy do we use?

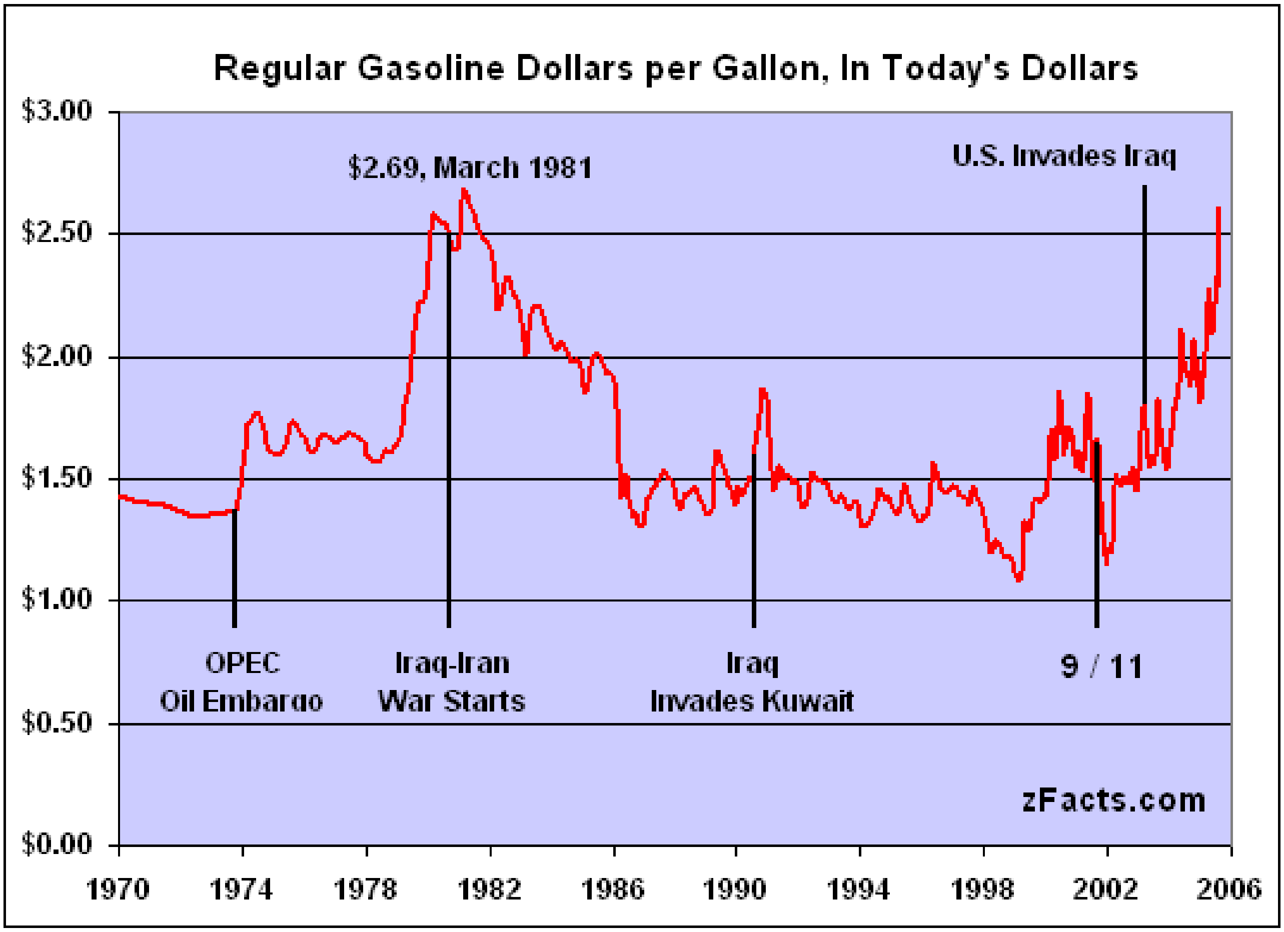
See the Statistical Review of World Energy 2005 by British Petroleum. Here is the powerpoint presentation (2.6 MB).

1. Global energy use in 2003 was 4.1 X 10^{20} Joules which is equivalent to 13 Terawatts.
   (a) 1 Terawatt (TW) = 10^{12} Joules/second= 10^{12} Watts.
   (b) The global energy use is equivalent to 71,000,000,000 barrels of oil equivalent used at the rate of 196,000,000 barrels of oil equivalent per day or the energy in 4.6 metric tons of mass converted into energy.
2. Global energy use from fossil fuels was approximately 8,260 million metric tons oil equivalent, which is approximately 9,623 X 10^6 m^3 = a cube of oil 2.12 km on a side.
3. Global oil consumption in 2003 was 76,800,000 barrels of oil per day.
   (a) Most of the remainder of our energy comes from natural gas and coal.
   (b) All are fossil fuels.
4. The per capita consumption of energy in the United States is about 57 barrels of oil equivalent per year or 11 kW continuously.
   (a) The energy is used to heat and light homes, offices, and stores, to power trucks and automobiles, and to operate machinery.
   (b) 57 barrels of oil at $50/barrel = $2,850.
   (c) If the energy were used entirely as electricity, it would cost about $7,300 per person per year.
5. Consumption of energy in the United States was approximately:
   (a) 39.1% oil
   (b) 25.9% natural gas
   (c) 24.4% coal
   (d) 8.1% nuclear energy
   (e) 2.5% hydroelectric, or
   (f) 89.4% from fossil fuel consumption.
6. The United States used approximately 24% of all the world's energy, although we are only 4.6% of the world's population.

Pathways of energy use in the United States in 2005. More than half of the energy produced is wasted (gray paths). Click on image for a zoom. Units are in quads: 1 quad = 10^{15} British thermal units = 1.055 exajoules = 1.0055×10^{18} Joules. From Whitesides (2007).

Why do we use so much fossil fuel?

We use fossil fuel because it is cheap relative to alternate sources of energy. Gasoline is cheaper than bottled water. Gasoline price in 2005 was just approaching the peak price of 1981.



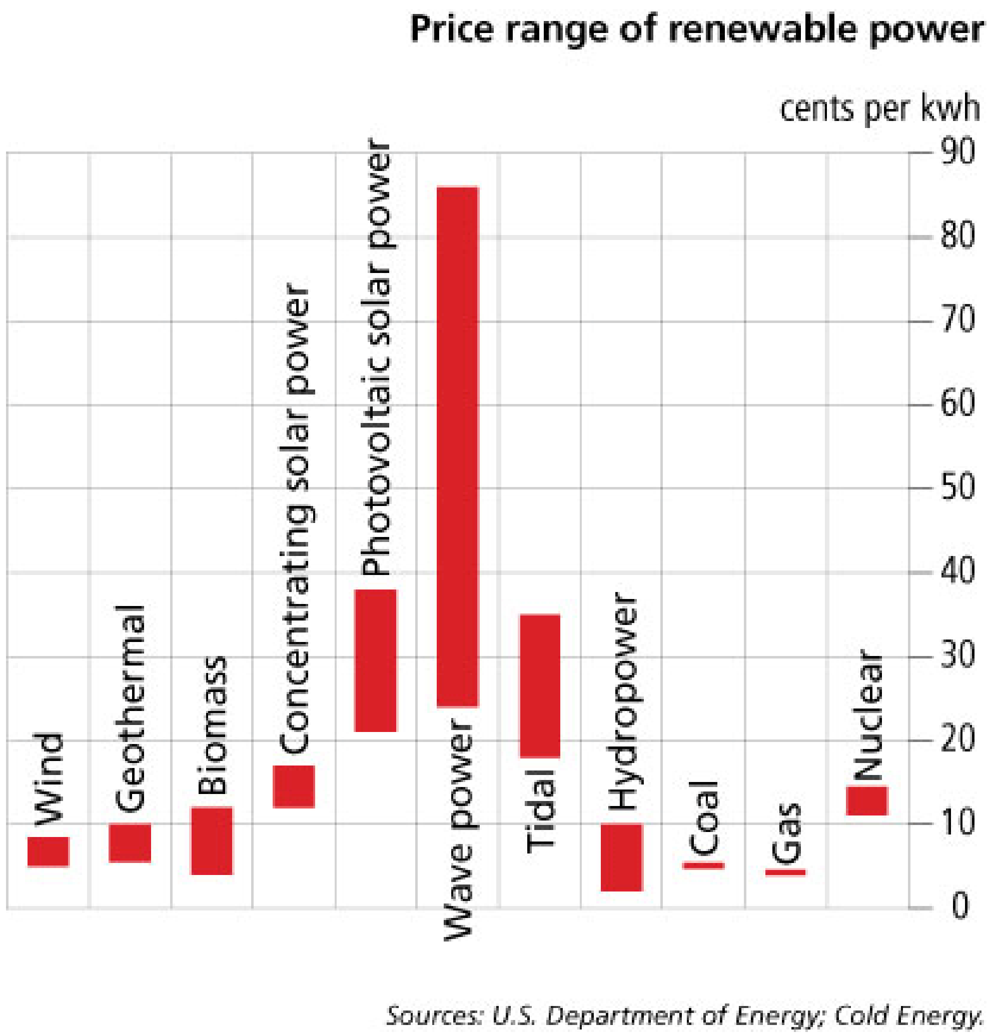
From zFacts.

Price is determined by:

1. Availability: Fossil fuels are abundant and easily extracted. The important question is: How long will they be abundant? The amount of known reserves divided by the rate of use has remained constant at around 40 years for more than 150 years. More recently, production has declined in many areas including the United States, Mexico, and western Europe. Many experts now claim world oil production has peaked and will begin to decline. This is known as Peak Oil.
2. Economics: Supply relative to demand is important.
   (a) As supply drops and demand increases, price increases.
   (b) Demand for oil is rising. The growth of the Chinese and Indian economies, and the increased use of oil by oil-exporting countries, has increased demand and reduced the supply of oil, driving up prices since 2005.
   (c) If oil and gas become even scarcer in the next few decades, and if world demand continues to rise, the price will increases greatly. As a result, use will drop, and release of CO_2 will drop, reducing the threat of global warming.
   (d) Also, as prices rise, more sources are found, demand drops, conservation and efficient use increase, and alternate fuels are used. As a result, we never run out of a commodity.
3. Politics: Political decisions and laws have a strong influence on price:
   (a) The Kyoto Protocol is a political solution to the CO_2 problem, and if implemented, it will increase costs.

(b) Governments tax fossil fuels to raise revenues and to reduce consumption.
(c) Many governments own oil companies and use the revenue to help run their countries.
(d) Some governments limit the availability of fossil fuels.
(e) Some governments regulate the use of the fuels.
(f) In the United States, Congress mandated in 2005 that ethanol be used in all gasoline. Ethanol is expensive, and not readily available. This raised gasoline prices in 2006.
(g) In the United States, many local and state governments have not allowed the construction of oil refineries. This limited the availability of gasoline and drove up price.

The cost of producing energy from alternative sources varies greatly, Nuclear energy is slightly more expensive than wind, geothermal, and biomass.



Price of energy from alternative sources compared with cost from fossil fuels. FromForbes Magazine (24 November 2008: page 64).

13.7 Future Energy Use

Some claim that it is economic suicide to base a nation's economy and prosperity on resources that can be depleted.

Recall that the Second Law of Thermodynamics (which states that the entropy of an isolated system which is not in equilibrium will tend to increase over time) reinforces this view of "renewable" and "non-renewable" resources: Energy flows downhill – gets used up, is transformed into heat; only materials that can be recycled are "renewable." It is only our time scale which makes any form of energy renewable. Eventually, the sun will burn out, as well.

Population growth, industrialization of developing countries, and advances in technology are placing increasing pressures on our rates of consumption of natural resources. Pollution and overexploitation foreshadow resource depletion, habitat loss, and atmospheric change. Unequal distribution of wealth, technology, and energy use (**Figure** 13.3) suggest that developing nations will further increase demands on natural resources. With these increases in demand, current levels of resource use cannot be maintained into the future, and social and political instability may increase. Improvements in technology could mitigate these problems to some extent.

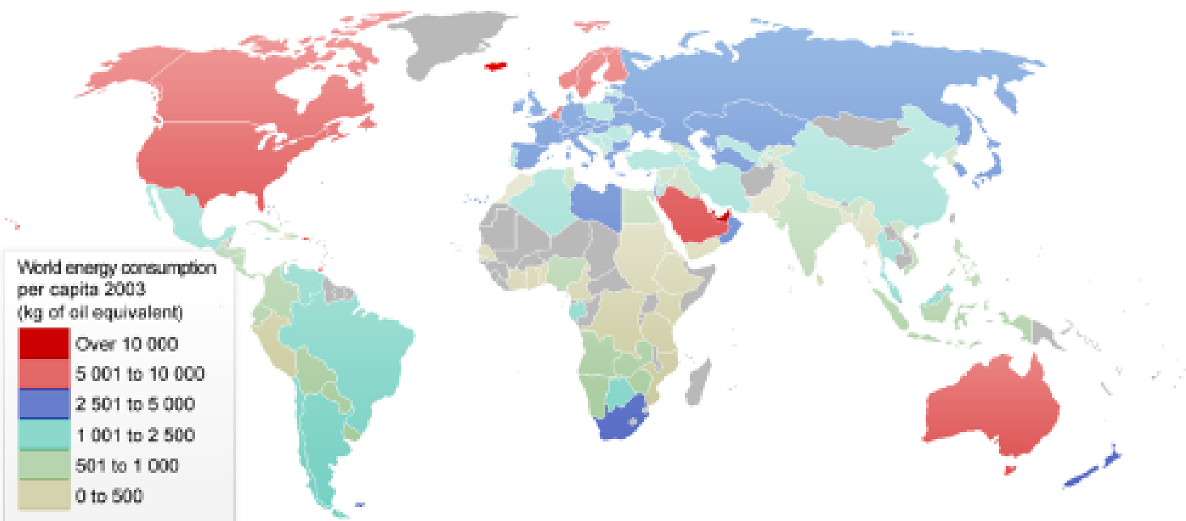


Figure 13.3: Per capita energy consumption illustrates the unequal distribution of wealth and natural resource use which threatens long-term resource supplies as developing nations demand higher standards of living. These inequalities threaten not only resource supplies but also global political stability.

The concept of renewable vs. non-renewable resources clearly depends on rates of human use (**Figure** 13.2); less clearly, its usefulness depends on the effects of use on other natural resources, such as pollution. Of course, we could change our rates of consumption. Indeed, if we increase our rate of consumption, renewable resources may need to be reclassified as non-renewable. This is the foundation of the concept of **sustainable use** – use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs. Notice that this concept continues to focus on human needs; however, a solid understanding of ecology recognizes that human needs depend on entire ecosystems, which in turn depend on all species. Sustainable use could also apply to ecosystem services, which can be overwhelmed by overuse even though their "use" does not involve consumption. Perhaps we should shift our natural resource focus from rate of consumption (renewable vs. non-renewable) to sustainable use!


Watch this video about renewable and non-renewable energy sources: Click here.

13.8 Highlight: Tragedy of the Commons

The concept of the Tragedy of the Commons is extremely important for understanding the degradation of our environment. The concept was clearly expressed for the first time by Garrett Hardin in his now famousarticle in Science in 1968, which is "widely accepted as a fundamental contribution to ecology, population theory, economics and political science." Hardin: University of California Santa Barbara.

Read the original article to Tragedy of the Commons in Science Magazine: http://www.sciencemag.org/content/162/38

Table 13.11:

 1963. From The Garrett Hardin Society.	Garrett Hardin, the author of Tragedy of the Commons, in

The Basic Idea

If a resource is held in common for use by all, then ultimately that resource will be destroyed. "Freedom in a common brings ruin to all." To avoid the ultimate destruction, we must change our human values and ideas of morality.

1. "Held in common" means the resource is owned by no one, or owned by a group, all of whom have access to the resource.
2. "Ultimately" means after many years, maybe centuries. The time interval is closely tied to population increase of those who have access to the resource. The greater the number of people using a resource, the faster it is destroyed. Thus the Tragedy of the Commons is directly tied to over population.
3. The resource must be available for use. Iron in earth's core is held in common, but it is inaccessible, and it will not be destroyed.
4. Resources held by individuals, even if the individual destroys the resource, is not an example of the Tragedy of the Commons.
5. Hardin used the word "tragedy" as the philosopher Whitehead used it: "The essence of dramatic tragedy is not unhappiness. It resides in the solemnity of the remorseless working of things." He [Whitehead] then goes on to say, "This inevitableness of destiny can only be illustrated in terms of

human life by incidents which in fact involve unhappiness. For it is only by them that the futility of escape can be made evident in the drama." Hardin (1968) Once the stage is set in a dramatic tragedy, there is no escape from the unhappy ending.

6. Note that the tragedy does not need to follow from greed. In the example below, we all breath the air. This degrades the common resource: air. But we breath not because we are greedy, but because we want to live. Any sustained increase of population in a finite biosystem ends in tragedy. In brief, tragedy is logically dependent only on the assumption that there is steady growth in the use of land or resources within any finite ecosystem; it is not logically dependent on the conventions of any specific political and economic system. From A General Statement of Hardin's Tragedy of the Commons by Herschel Elliott.
7. We can avoid tragedy only by altering our values, by changing the way we live. There is no technical solution. The general statement of the tragedy of the commons demonstrates that an a priori ethics constructed on human-centered, moral principles and a definition of equal justice cannot prevent and indeed always supports growth in population and consumption. Such growth, though not inevitable, is a constant threat. If continual growth should ever occur, it eventually causes the breakdown of the ecosystems which support civilization. ... Specifically, Hardin's thought experiment with an imaginary commons demonstrates the futility – the absurdity – of much traditional ethical thinking. From A General Statement of Hardin's Tragedy of the Commons by Herschel Elliott. We will not delve further into the ethical implications. They are profound and far reaching.

Garrett rephrased his idea in 1985:

> As a result of discussions carried out during the past decade I now suggest a better wording of the central idea: Under conditions of overpopulation, freedom in an unmanaged commons brings ruin to all. From Hardin (1985) An Ecolate View of the Human Predicament.

Examples of Common Resources

1. Air. No one owns the air, it is available for all to use, and its unlimited use leads to air pollution.
2. Water. Water in the seas, estuaries, and the ocean is a common resource. But, water in lakes and rivers is often owned by cities, farmers, or others, especially in the western US.
3. Fish of the sea. Hardin writes that In 1625, the Dutch scholar Hugo Grotius said, "The extent of the ocean is in fact so great that it suffices for any possible use on the part of all peoples for drawing water, for fishing, for sailing." Now the once unlimited resources of marine fishes have become scarce and nations are coming to limit the freedom of their fishers in the commons. From here onward, complete freedom leads to tragedy.

Some History

The concept that air, water, and fish are held in common for use by all was first codified into law by the Romans. In 535 AD, under the direction of Tribonian, the Corpus Iurus Civilis [Body of Civil Law] was issued in three parts, in Latin, at the order of the Emperor Justinian: the ***Codex Justinianus***, the ***Digest***, or *Pandects*, and the ***Institutes***. The ***Codex Justinianus*** (issued in 529 AD) compiled all of the extant (in Justinian's time) imperial constitutions from the time of Hadrian. It used both the Codex Theodosianus and private collections such as the Codex Gregorianus and Codex Hermogenianus. From: The "Codex Justinianus" Medieval Sourcebook: The Institutes, 535 CE. Here is the pertinent text:

Codex Justinianus (529) (Justinian Code), Book II, Part III. The Division of Things:

1. By the law of nature these things are common to mankind—the air, running water, the sea, and consequently the shores of the sea. No one, therefore, is forbidden to approach the seashore, provided that he respects habitationes, monuments, and buildings which are not, like the sea, subject only to the law of nations.

2. All rivers and ports are public; hence the right of fishing in a port, or in rivers, is common to all men.

3. The seashore extends as far as the greatest winter flood runs up. ...

5. The public use of the seashore, too, is part of the law of nations, as is that of the sea itself; and, therefore, any person is at liberty to place on it a cottage, to which he may retreat, or to dry his nets there, and haul them from the sea; for the shores may be said to be the property of no man, but are subject to the same law as the sea itself, and the sand or ground beneath it. ...

12. Wild beasts, birds, fish and all animals, which live either in the sea, the air, or the earth, so soon as they are taken by anyone, immediately become by the law of nations the property of the captor; for natural reason gives to the first occupant that which had no previous owner. And it is immaterial whether a man takes wild beasts or birds upon his own ground, or on that of another. Of course any one who enters the ground of another for the sake of hunting or fowling, may be prohibited by the proprietor, if he perceives his intention of entering. From: The "Codex Justinianus" Medieval Sourcebook: The Institutes, 535 CE.

A General Statement of the Tragedy of the Commons

The philosopher Herschel Elliott states that there are four general premises that entail the tragedy of the commons:

1. The Earth is finite: it has a limited stock of renewable fuels, minerals, and biological resources, a limited throughput of energy from the sun, and a finite sink for processing wastes.
2. Although human activity very often does occur on privately owned lands which are not a commons, that and all other human activities take place in some larger natural commons. And that larger commons is a limited biosystem which is in a dynamic, competitive, and constantly evolving equilibrium. The equilibrium of an ecosystem can usually accommodate any activity on the part of its members as long as that activity is limited in amount and/or is practiced only by a small population. But continuous growth in the numbers of any organism or in its exploitation of land and resources will eventually exceed the capacity of the ecosystem to sustain that organism.
3. Now for the first time on global scale human beings are exceeding the land and resource use which the Earth's biosystem can sustain.
4. Certainly it is true, as Hardin noted, that individuals who seek to maximize their material consumption contribute to the ever increasing exploitation of the world's commons. But it is also true that all who follow the rarely questioned principles of humanitarian ethics – to save all human lives, to relieve all human misery, to prevent and cure disease, to foster universal human rights, and to assure equal justice and equal opportunity for everyone – do so also.

From A General Statement of Hardin's Tragedy of the Commons by Herschel Elliott.

Some Consequences

The large and rapid increase in population since the beginning of the anthropocene has altered the global commons. Will our atmosphere, rivers, lands, and ocean ultimately be destroyed because they are held in common for use by all? Will we place ever stronger restrictions on their use? Or will we limit the population of the world?

> Its message is, I think, still true today. Individualism is cherished because it produces freedom, but the gift is conditional: The more the population exceeds the carrying capacity of the environment, the more freedoms must be given up. As cities grow, the freedom to park is restricted by the number of parking meters or fee-charging garages. Traffic is rigidly controlled. On the global scale, nations are abandoning not only the freedom of the seas, but the freedom of the atmosphere, which acts as a common sink for aerial garbage. Yet to come are many other restrictions as the world's population continues to grow. – Hardin (1998): Extensions of "The Tragedy of the Commons."

Jared Diamond in his book Collapse describes in detail the collapse of civilizations that failed to solve the problem of the Tragedy of the Commons. He writes of Pitcairn and Henderson Islands in the Pacific (page 120):

> Many centuries ago, immigrants came to a fertile land blessed with apparently inexhaustible resources. While the land lacked a few raw materials useful for industry, those materials were readily obtained by overseas trade with poorer lands that happened to have deposits of them. For a time, all the lands prospered, and their populations multiplied.
>
> But the population of that rich land eventually multiplied beyond the numbers that even its abundant resources could support. As its forests were felled and its soils eroded, its agricultural productivity was no longer sufficient to generate export surpluses, build ships, or even to nourish its own population. With that decline of trade, shortages of the imported raw materials developed. Civil war spread, as established political institutions were overthrown by a kaleidoscopically changing succession of local military leaders. The starving populace of the rich land survived by turning to cannibalism. Their former overseas trade partners met an even worse fate: deprived of the imports on which they had depended, they in turn ravaged their own environment until no one was left alive.

Solutions

Tragedy is not inevitable. Jared Diamond described how some societies avoided tragedy, at least locally. The people of Tikopia, Japan, and the New Guinea highlands saved their forests and the agrarian economy which depended on forests. All limited their population to what could be sustained by their economy.

Hardin points out that the Tragedy of the Commons is an example of the class of problems with no technical solution, where:

> A technical solution may be defined as one that requires a change only in the techniques of the natural sciences, demanding little or nothing in the way of change in human values or ideas of morality. Hardin (1968).

We Must Change Our Values: Mutual Coercion

Therefore, any solution requires that we, as a society, change our values of morality. For example, we may decide that unlimited use of air is no longer morally acceptable. Hardin states one solution is "Mutual Coercion Mutually Agreed Upon." We, as a society, agree that some actions are not allowed (the mutual agreement), and that violations of the agreement leads to fines or prison terms (the Coercion). Thus, we have some restrictions on what can be put into the air. The US Environmental Protection Agency regulates the amount of pollutants that can be released into the air. Failure to comply with the regulations leads to fines or prison sentences.

Hawaiian Islanders protected their environment and fisheries for a thousand years by a unique system of local ownership extending from the sea to the headwaters of streams feeding into the sea. Violations of the rules (taboos) could lead to the death penalty. This was "mutual coercion mutually agreed upon" in the extreme.

Table 13.12:

Hawai'ian islanders punishing a guilty person. Lithograph by Langlame: Maniere de punir de mort un coupable aux iles Sandwich. Published in the book by Jacques Etienne Victor Arago, Promenade autour du monde (pendant les annees de 1817, 1818, 1819 et 1820, sur les corvettes du Roi l'Uranie et la Physicienne, commandees par M. Freycinet. From Grosvenor Prints Hampton, UK.

More General Solutions

In addition, morals or ethics can lead to changes in use of the resource. How can this be done? Ostrom et al (1999) provide a possible answer.

> "Solving [commons] problems involves two distinct elements:
>
> 1. Restricting access, and
> 2. Creating incentives (usually by assigning individual rights to, or shares of, the resource) for users to invest in the resource instead of overexploiting it.
>
> Both changes are needed. For example, access to the north Pacific halibut fishery was not restricted before the recent introduction of individual transferable quotas and catch limits protected the resource for decades. But the enormous competition to catch a large share of the resource before others did resulted in economic waste, danger to the fishers, and reduced quality of fish to consumers. Limiting access alone can fail if the resource users compete for shares, and the resource can become depleted unless incentives or regulations prevent overexploitation." From Ostrom et al (1999), "Revisiting the Commons: Local Lessons, Global Challenges."

Restricting access ultimately involves limiting population, especially when the common being accesses is a global system.

13.9 End of Chapter Review & Resources

Chapter Summary

One's definition of natural resources clarifies human relationships and responsibilities to the Earth. Robert Hartwell's definition defines natural resources as: "something supplied by nature which supports life on this planet." This definition includes ecosystems, ecosystem services, biodiversity, energy sources and raw materials. Renewable resources are replenished by natural processes as fast as, or faster than humans consume them. A non-renewable resource is not regenerated or restored on a time scale comparative to its consumption. Fossil fuels are a classic example of nonrenewable resources. In practice, pressure from growing populations and increasing industrialization can lead to overconsumption and/or degradation, changing a renewable resource into a non-renewable resource. According to the Laws of Energy, energy resources are not renewable because they get used up, but materials or matter is constant because it can theoretically be recycled. The concept of sustainable use – the use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs – may be more helpful in decision making. The world's current energy use is unsustainable, especially if increases in developing countries are considered. Worldwide, conversion of forests to other uses, especially by slash-and-burn, adds CO_2 to the atmosphere and reduces the potential for absorption of CO_2 by photosynthesis, adding to greenhouse gases. Local, national, and international organizations can work to promote awareness and encourage action.

Review Questions

1. What is your own concept of natural resources? What relationship between humans and the Earth does it contain?
2. Distinguish between renewable and nonrenewable resources, and relate these concepts to the Laws of Energy.
3. Classify the following resources as renewable or nonrenewable: coal, copper, iron, natural gas, nuclear power, oxygen, sunlight, water, wood, wool. Briefly explain your reasoning for each resource.
4. List renewable resources.
5. List non-renewable resources.
6. Define what is the Tragedy of the Commons.

Further Reading / Supplemental Links

- The original article to Tragedy of the Commons in Science Magazine: http://www.sciencemag.org/content/162/3
- Bob Hartwell, "Natural Resource Definition." US Department of Energy *NEWTON Ask* A Scientist, 4 February 2005. Available online at:
- http://www.newton.dep.anl.gov/askasci/gen01/gen01773.htm
- Schumacher, E. F., "Small Is Beautiful: Economics As If People Mattered : 25 Years Later...With Commentaries," 1999. Hartley & Marks Publishers.
- http://www.wri.org/
- http://www.energy.gov/energysources/index.htm

Vocabulary to Know

- acid rain - Precipitation in any form which has an unusually low pH.

- natural resource - Something supplied by nature which supports life, including sources of energy and materials, ecosystems, and ecosystem services.
- nonrenewable resource - A resource which is not regenerated or restored on a time scale comparative to its consumption.
- renewable energy sources - Sources of energy which are regenerated by natural sources within relatively short time periods, e.g. solar, wind, and geothermal, as opposed to fossil fuels.
- renewable resource - A resource which is replenished by natural processes at a rate roughly equal to the rate at which humans consume it.
- sustainable use - Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs.

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Chapter 14

Air Pollution

14.1 Introduction

Air: so easy to take for granted. In its pristine state, we cannot see it, smell it, taste it, feel it, or hear it, except when the wind blows or clouds form. Yet its complex and dynamic mix of gases is essential for life. Air pollution causes far reaching problems beyond just 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.

Lesson Objectives

- Recognize that the Earth's atmosphere provides conditions and raw materials essential for life.
- Review the changes in the atmosphere over the history of the Earth.
- Describe the dynamic equilibrium which characterizes the natural atmosphere.
- Analyze the ways in which population growth, fossil fuel use, industrialization, technology, and consumption result in atmospheric changes.
- Explain the effects of these changes on ecosystems.
- Relate these effects to current global stability.
- Describe how human activities including technology affect ecosystem services such as:

- Evaluate the effects of changes in these services for humans.
- Identify the ways in which humans have altered the air for other species.
- Relate air pollution to ecosystem loss.
- Interpret the effects of air pollution on biodiversity.
- Define acid rain.
- List the natural and anthropogenic causes of acid rain.
- Identify the effects of acid rain.
- Discuss solutions specific to the problem of acid rain.
- Locate and describe the origin of the ozone layer.
- Distinguish between ozone depletion and the ozone hole.
- Explain the role of ozone in absorbing ultraviolet radiation.
- Indicate the ways in which the ozone layer varies naturally.
- Discuss the relationship between recent changes in the ozone layer and human activities.
- Describe the measures taken to restore the ozone layer and evaluate their effectiveness.

14.2 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** 14.1). 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.

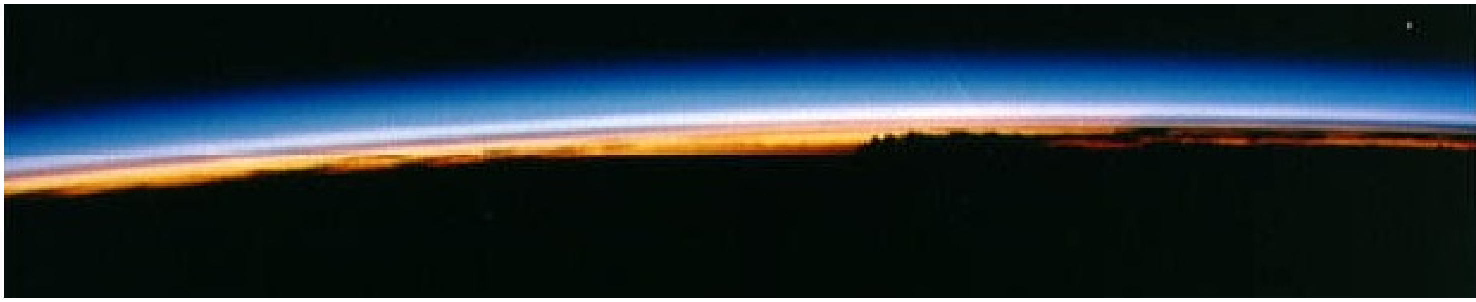
Figure 14.1: A composite photo of satellite images shows Earth and its life-supporting waters and atmosphere.

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.

Table 14.1:



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.

Remember ”Good Up high, Bad Nearby”

14.3 Upsetting the Equilibrium of the Atmosphere: Air Pollution

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** 14.2). 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** 14.3).

Figure 14.2: Burning fossil fuels

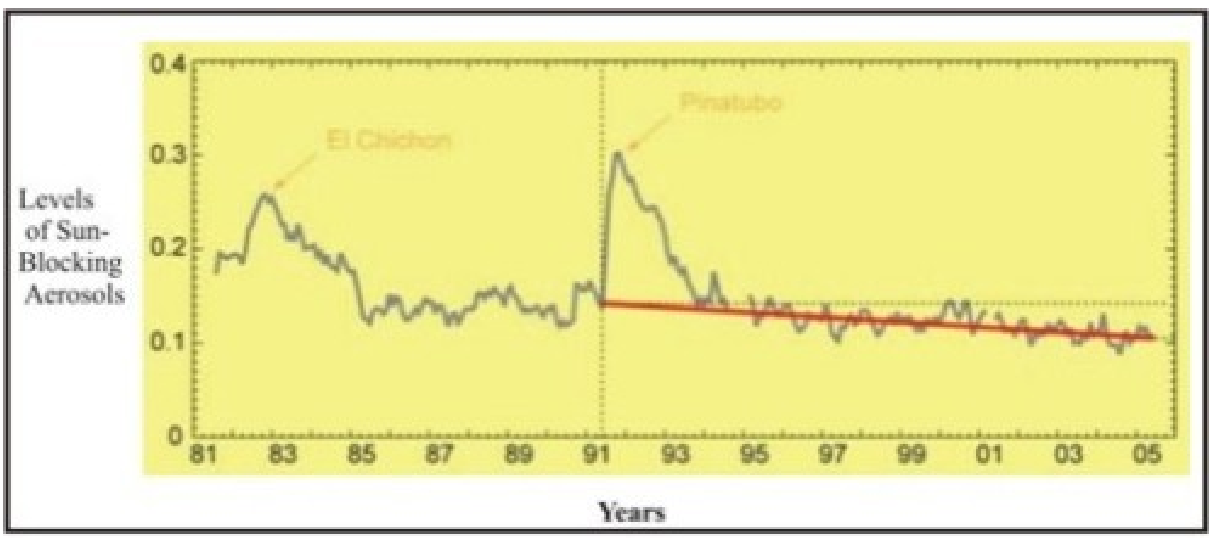


Figure 14.3: Levels of sun-blocking aerosols declined from 1990 to the present. A corresponding return to pre-1960 levels of radiation suggests that pollution control measures in developed countries have counteracted Global Dimming. However, particulates are still a problem in developing countries, and 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** 14.2.

Table 14.2:

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

Table 14.2: (continued)

Pollutant	Example/Major Source	Problem
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

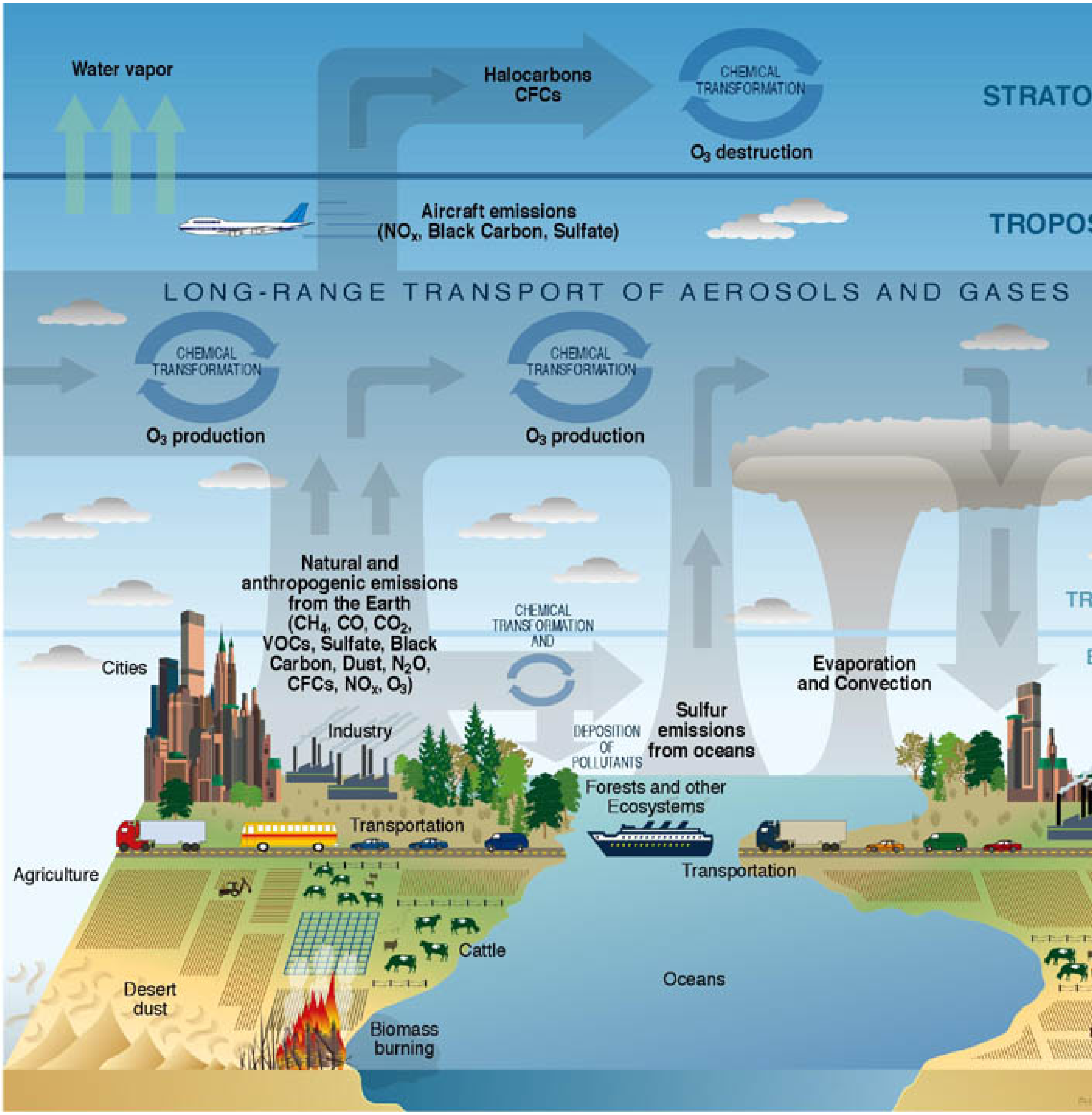
Beyond the burning of fossil fuels, other **anthropogenic** (human-caused) **sources** of air pollution are shown in **Table** 14.3.

Table 14.3:

Activity	Pollutant	Problem
Erosion Herbicides and Pesticides Fertilizers Agriculture: Cattle Ranching	Dust Persistent Organic Pollutants(POP): DDT, PCBs, PAHs* Ammonia (NH_3), Volatile Organic Chemicals(VOCs) Methane (CH_4)	Global Dimming Cancer Toxicity, Global Warming Global Warming
Refrigerants, Aerosols Industry (solvents, plastics)	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

Table 14.4:



Many processes contribute to atmospheric pollution and trace gases. Click on image for a zoom. From US Strategic Plan for the Climate Change Science Program, Final Report July 2003: Chapter 3 Atmospheric Composition.

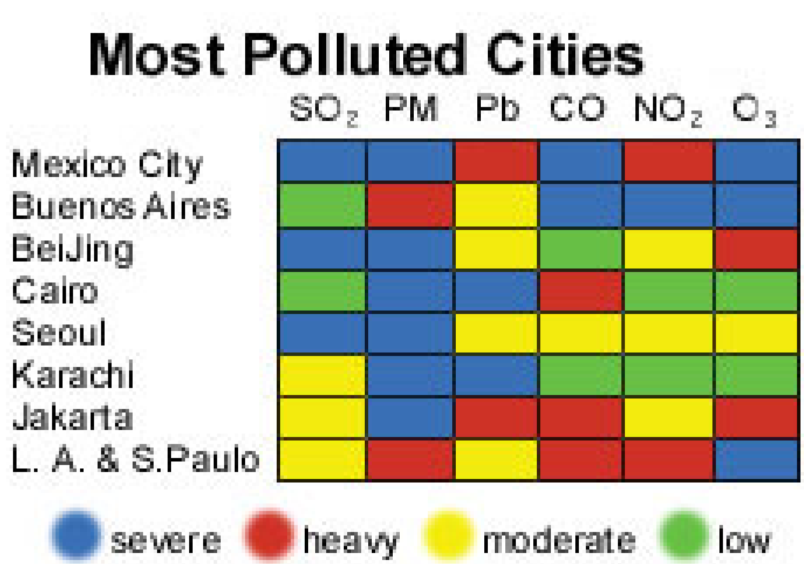
http://oceanworld.tamu.edu/resources/environment-book/Images/Atmosphere_composition_ diagram.jpg

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:
   (a) Hydrocarbons. They come from the evaporation of fuel, especially on hot days, leaking fluids, and during refueling at gas stations.
   (b) Nitrogen oxides. Produced by high heat during the burning of fuel.
   (c) 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.

Table 14.5:



From Air Pollution in Mexico City by Pierre Madl of Salzburg University Sound and Video Studio. It is caused not only by emissions from cars, trucks, buses and lawnmowers (operating a lawn mower for one hour produces as much pollution as driving a car 100 miles), but also by fumes from drying paint, charcoal fires (grills), and dry cleaners.

A huge traffic jam backs up the streets in Bangkok. High population density in large urban areas leads to air pollution. Click on 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).

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

This is what the smog in Los Angeles looks like from the ground, a thick brown or slightly orange haze with a strong smell of ozone. In this scene, the inversion is below the top of the highest buildings. The exhaust from more than a million cars driven in the morning rush hour is trapped below this level. Click on image for a zoom. From Larvalbug article Choking on Air.

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

Agricultural burning.

Crop burning, Alberta Canada. Click on image for a zoom. FromAg-Info Centre, Government of Alberta, Canada.

Forest fires.

Wildfires and smoke on 23 October 2007 in southern California. The fires burned 800 square miles, and area almost 2/3 the size of Rhode Island. The smoke from the fires is clearly visible over the Pacific ocean on the left of the image. Red spots mark the location of the fires. Click on image for zoom. From NASA California Wildfires. Other similar images are at the NOAA site: Operational Significant Event Imagery. NOAA issues dailyFire Products, including a map showing all forest fires in North America, and information of **Fire Events** worldwide.

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.

V.I. Lenin Steel mill, Magnitogorsk, 1991. From Monroe Gallery of Photography, photographed by Shepard Sherbell. Dust storms. Strong winds blowing across desert regions lift dust high into the troposphere. The higher-level winds then carry dust great distances. The Sahara, the Aral Sea, and Mongolia are notorious sources.

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 colored yellow-brown in the image. From NOAA Dust Storm site. NASA has a catalog of images of dust storms.

Many pollutants travel indoors.

Pollutants from the air tralel 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 (**Figure** 14.3). 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** 14.4). 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.

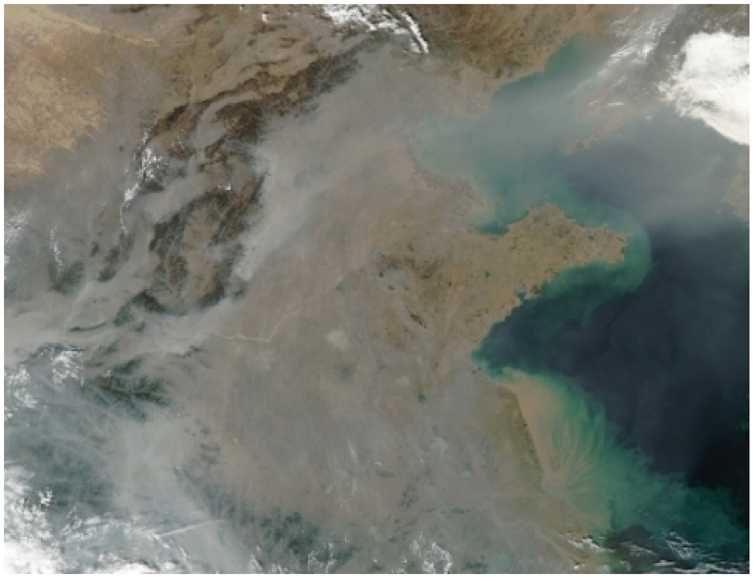


Figure 14.4: A cloud of smoke and haze covers this region of China from Beijing (top center) to the Yangtze River (bottom right). At the top right, pollution is blowing eastward toward Korea and the Pacific Ocean. Aerosol pollution with large amounts of soot (carbon particles) is changing precipitation 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** 14.5) 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**.

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

Many cities, especially those near observatories, are switching to low-pressure sodium lamps, because their light is relatively easy to filter.

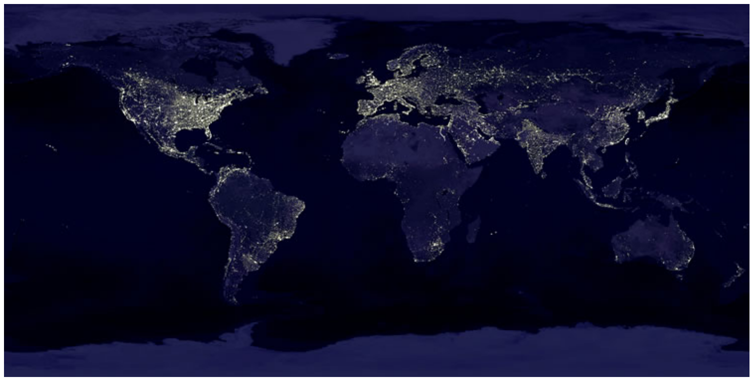
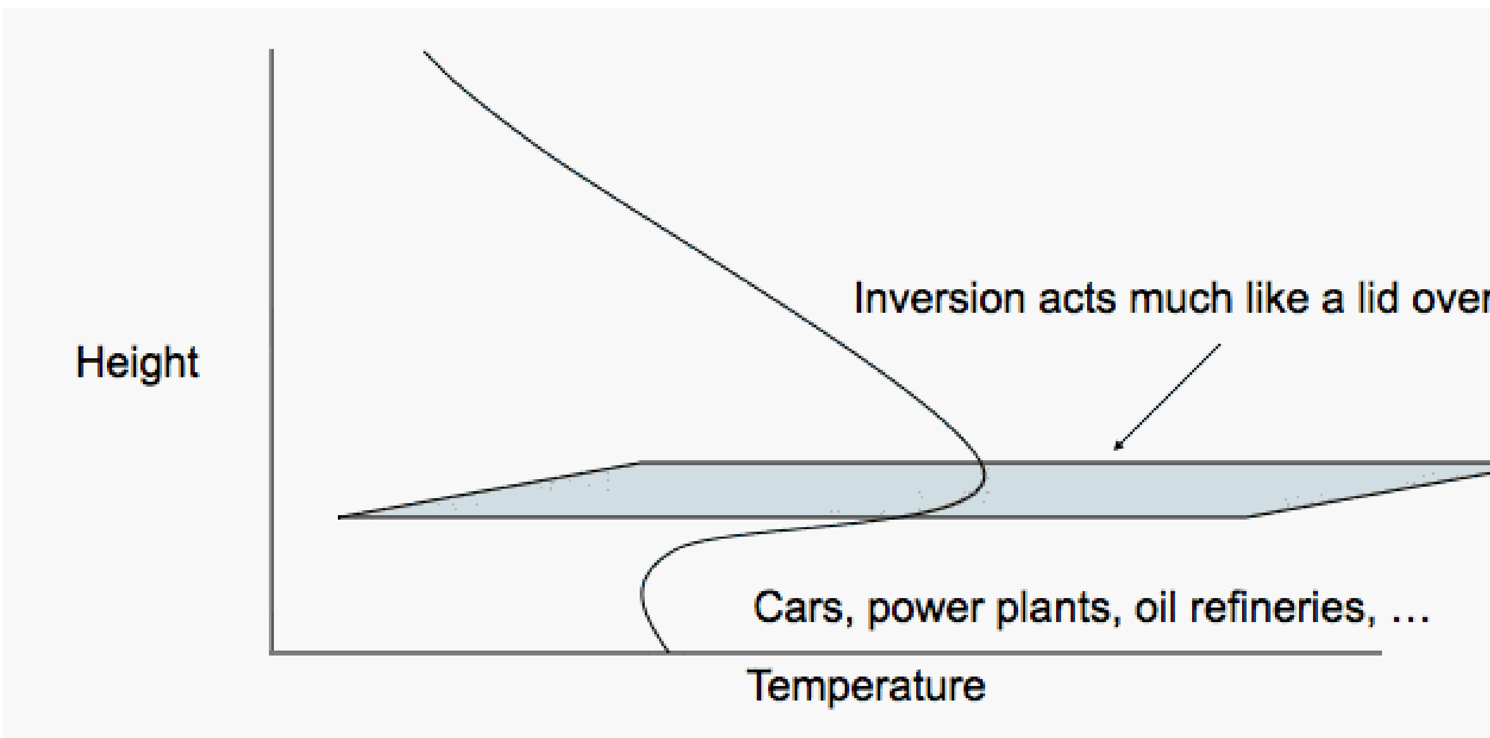


Figure 14.5: When light produced by humans becomes annoying, wasteful, or harmful, it is considered light pollution. This composite satellite image of Earth at night shows that light is concentrated in urban

Inversions

Inversions strongly influence atmospheric pollution. Inversions inhibit vertical convection, trapping pollutants close to the surface. Strong, persistent, inversions over urban areas lead to much greater concentrations of pollutants in the urban air.



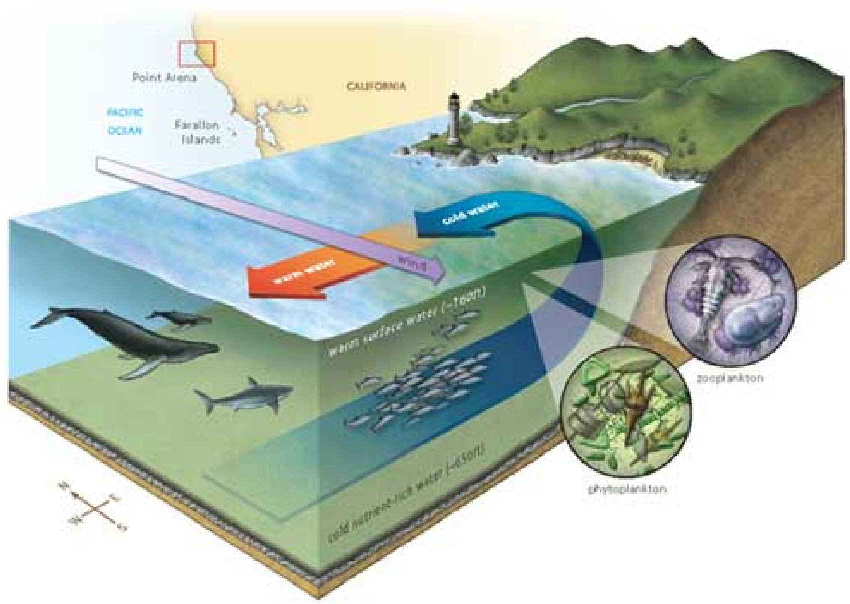
Inversions:

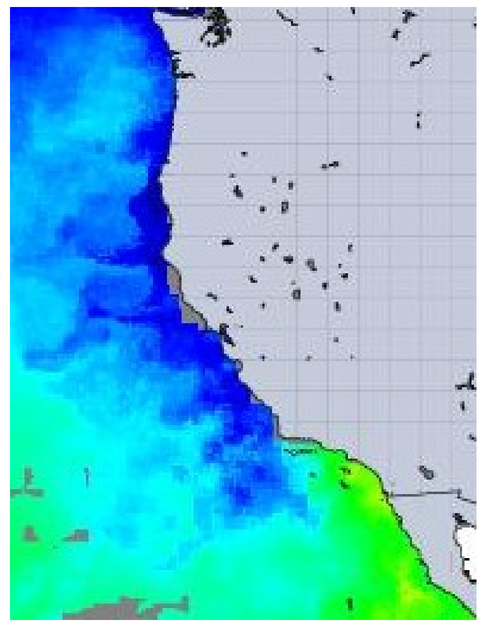
1. Limit vertical mixing. This traps pollutants close to the ground.
2. Limit cloud formation. This leads to more sunlight, which drives chemical reactions in the polluted air.
3. Limits precipitation. This increases the lifetime of the pollutants in the atmosphere.

Inversions are common along west coasts of continents. There winds blowing toward the equator (purple arrow in figure below left) cause water at the ocean's surface to move away from the coast (red arrow). The water is replaced by colder water upwelled from deeper in the ocean (blue arrow). The cold water cools the lower kilometer of the atmosphere, producing the inversion. Strong inversions are common along the California coast. They are responsible for the warm, dry, cool climate of Los angeles, San Francisco, and San Diego. They are also responsible for smog commonly found in these cities, especially Los Angeles. For more, read at Applications of Ekman Theory.

Inversions also occur above inland lakes and rivers on days when the water is cooler than the air, and winds are weak, and in valleys at night when colder air drains off surrounding hills.

Table 14.20:





Right: Sea-surface temperature along the US west coast on 16-18 July 2006 measured by the Advanced High Resolution Radiometer AVHRR on the NOAA polar-orbiting, meteorological satellites. The cold (blue) areas are upwelled water caused by north winds offshore of the coast. Click on the image for a zoom with color scale. From NOAA CoastWatch. Left: Schematic diagram showing equatorward winds along the California coast (purple arrow) push water offshore (red arrow), leading to upwelling of colder water along the coast (blue arrow) shown in the figure on the right above. The cold water not only influences the atmosphere, but it also carries nutrients that increase the productivity of the area. Click on the image for a zoom. From Bay Nature: A Moveable Feast: The Ups and Downs of Coastal Upwelling. Drawing by Fiona Morris.

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

14.4 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** 14.6).

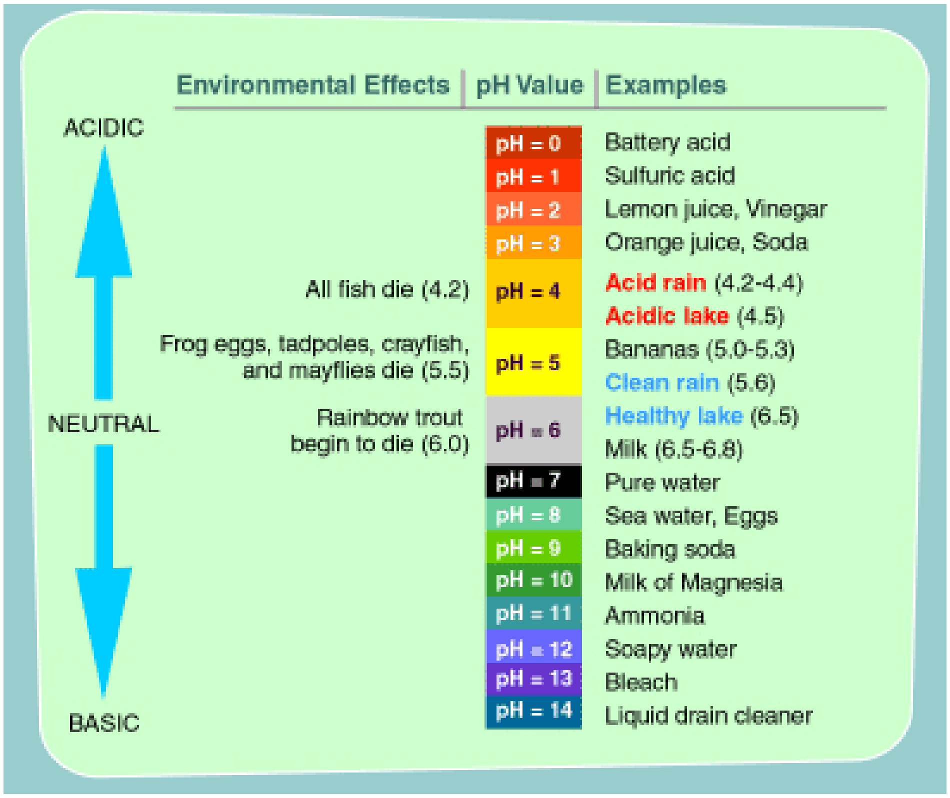
Acidity of precipitation is measured in pH units, where

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

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.

$$H_2O + CO_2 \text{ –> } H_2CO_3$$

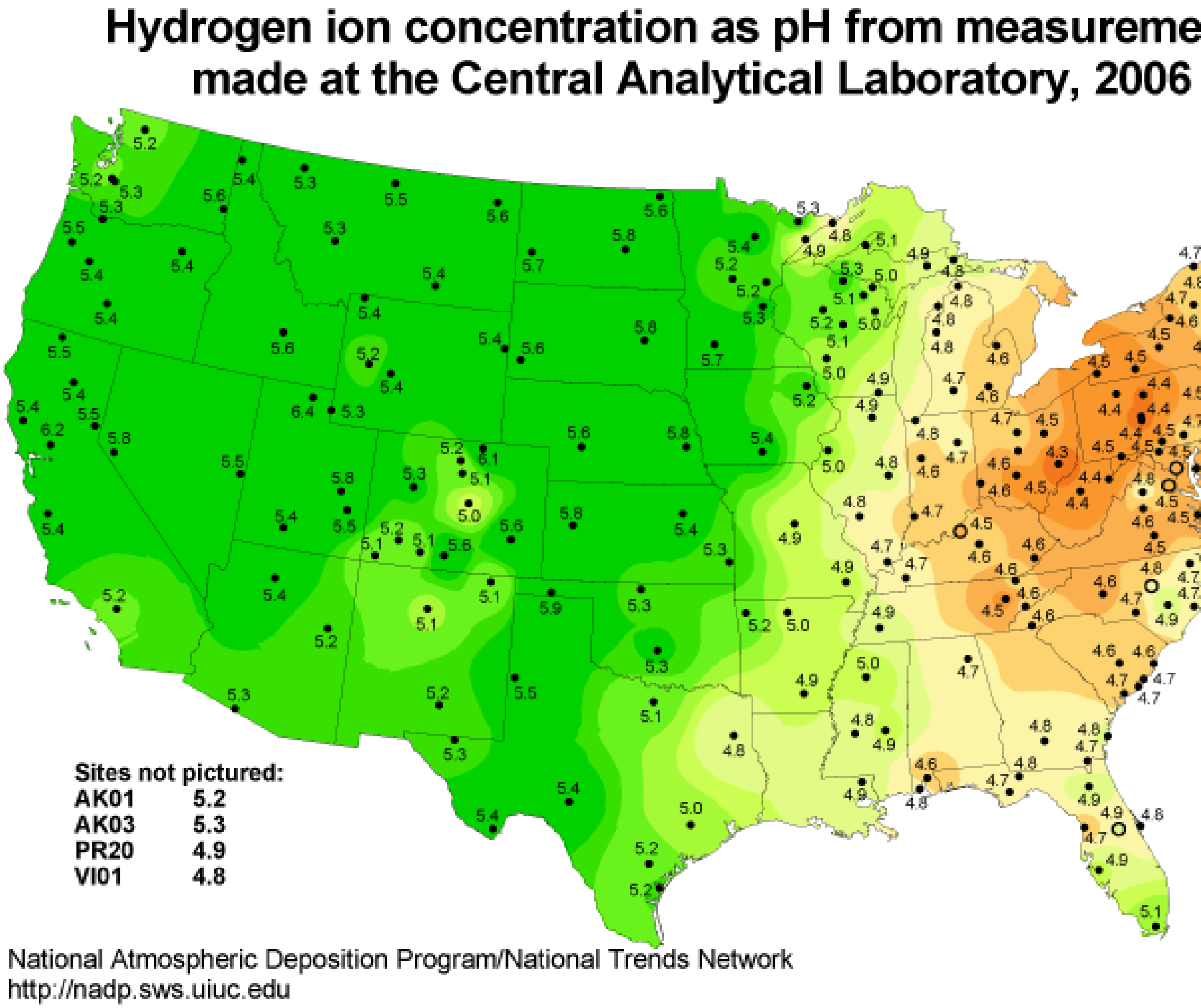
Table 14.21:



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.

Table 14.22:



Acidity of precipitation measured by the National Atmospheric Deposition Program in 2006. Notice that precipitation is most acidic downwind of the large concentration of power plants in the Ohio Valley.

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.

Table 14.23:

	
Left: Coal-fired power plants emit large quantities of acid pollutants into the atmosphere, although the volume of pollutants has been decreasing as scrubbers that remove pollutants from exhaust gases have become more widely used. The image shows exhaust from the American Electric Power's Gen. James M. Gavin Plant in Chesire in Gallia County, in the Ohio Valley. It is one of the largest coal-fired power plants in Ohio. Most of the visible exhaust is condensed vapor, but the brownish haze includes acids. From Ohio.Com of the Akron Beacon Journal, article Ohio EPA cites area for soot problems. Right: Scrubber at base of Georgia Power's Bowen Plant removes 95% of the sulfur dioxide in the plant's exhaust gas. Click on the image to bring up a diagram of how a scrubber works from Scrubber freshens smokestack by Wade Rawlins, 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:

Table 14.24:

CO_2	$+ H_2O$	H_2CO_3	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.

Table 14.25:

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

Table 14.26:

SO_3	$+ H_2O$	$\rightarrow H_2SO_4$	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 $\times 10^6$ metric tons in 1978 to 17.8 $\times 10^6$ metric tons in 1998.

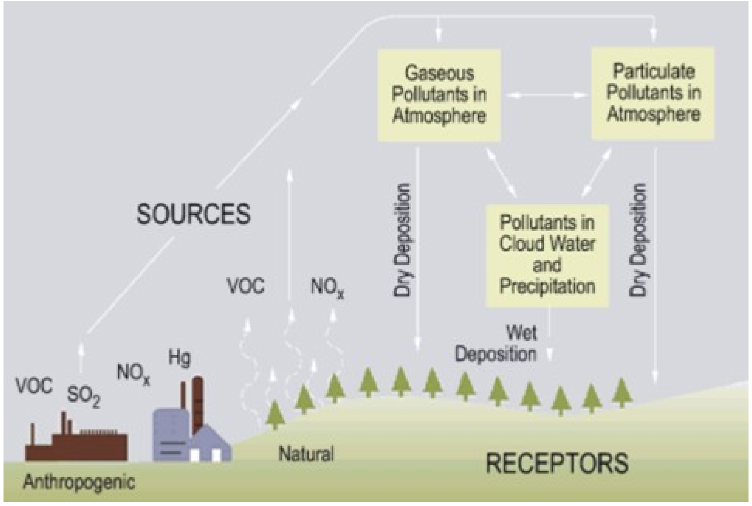
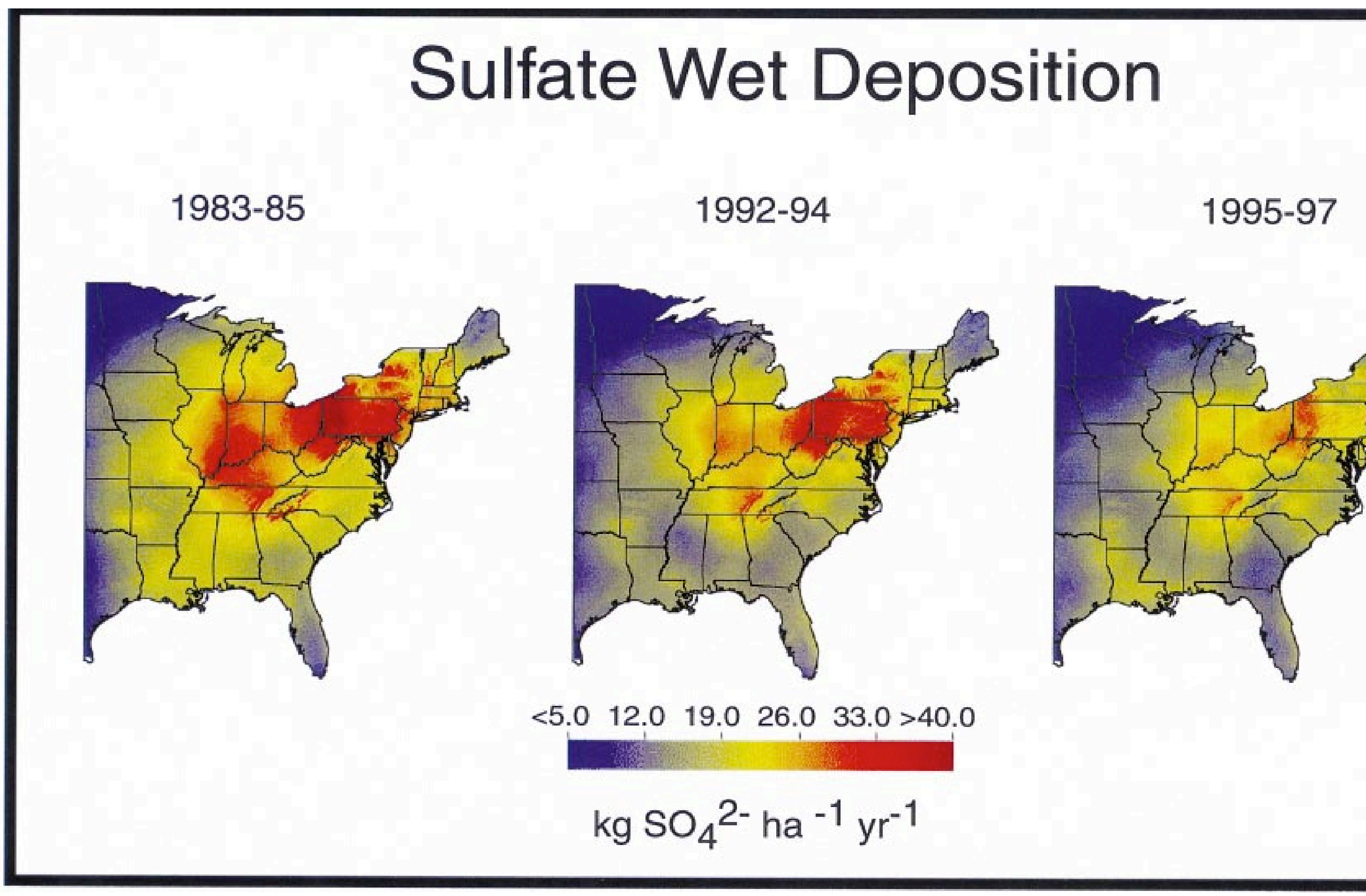


Figure 14.6: formation begins when nitrogen and sulfur oxides (here NO

Table 14.27:



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

Figure 14.7: 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.

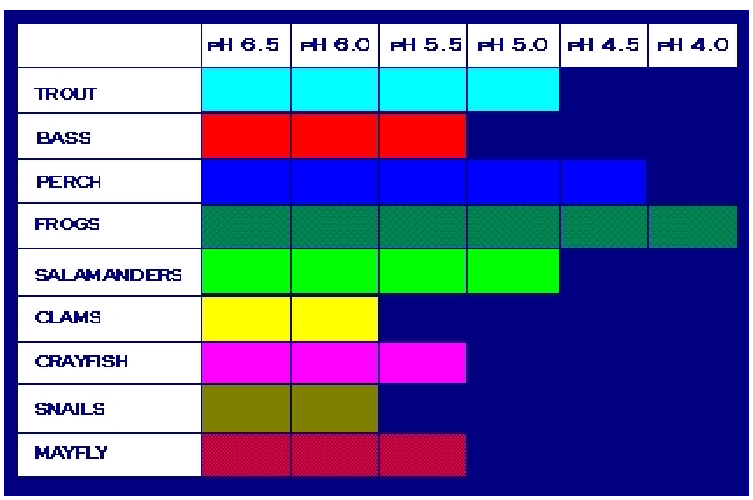


Figure 14.8: Aquatic species show varying sensitivity to pH levels. Colored bars show survival ranges. Trout are more sensitive to increasing acidity than frogs, but mayflies, which frogs consume, are even more sensitive. Consequently, changes in a lake

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.

> Some of the most dramatic effects on forests have been observed in Europe. In 1983, a survey in West Germany showed that 34% of the country's total forest is damaged by air pollution. This included about one half of the famous Black Forest. Switzerland has recorded damage to 14 % of her forest trees... Vogelmann, measured the reproductive capacity of the forest by counting the total trees in an area. Red spruce dropped from 6,000 trees to 1,000 trees, a decline of 80 % from 1965 to 1983. Very few pine cones and young trees were found. Sugar maple tree counts dropped 84 % and beech tree counts dropped 63% over the same time period... Acid rain or acid cloud droplets that fall on the leaves and needles of trees leaches the nutrients from them. Calcium, magnesium, and potassium ions may be removed from the leaves faster than the roots can resupply them. Acid rain in combination with ozone may damage the waxy coating on leaves and needles. This may weaken, damage them, and provide opportunities for diseases to enter the tree. From Virtual ChemBook Elmhurst College Charles E. Ophardt Acid Rain Effects on Forests.

Effect on Aquatic Animals

When nutrients and metals, including heavy metals and aluminum, are leached from the soil, they are carried by runoff and groundwater into streams and lakes where they kill aquatic life. Aluminum dissolved by acid rain is highly toxic to many aquatic animals, especially young animals including eggs and larvae.

Not all species of animals are equally sensitive to acids and aluminum. Some fish species (such as (brown bullhead, yellow perch, golden shiner, brook trout, and white sucker) are tolerant of water with $pH < 6$, while others (such as Atlantic salmon, tiger trout, redbreast sunfish, bluegill, tiger musky, walleye, and alewife) cannot tolerate such waters. Most fish are killed if pH falls below 5.2 (Driskoll, 2001).

> In areas where soils have little capacity to buffer acids in water, acidic precipitation can be a problem because the infiltrating acidic water can increase the solubility of metals, which results in the flushing of high concentrations of dissolved metals into surface water. Increased concentrations of naturally occurring metals such as aluminum may be toxic to aquatic organisms. Studies of watersheds have indicated that the length of subsurface flow paths has an effect on the degree to which acidic water is buffered by flow through the subsurface. For example, studies of watersheds in England have indicated that acidity was higher in streams during storms when more of the sub-surface flow moved through the soil rather than through the deeper flow paths. Moreover, in a study of the effects of acid precipitation on lakes in the Adirondack Mountains of New York, the length of time that water was in contact with deep subsurface materials was the most important factor affecting acidity because contact time determined the amount of buffering that could take place. – US Geological Survey. Circular 1139, Ground Water and Surface Water A Single Resource. Effects of Atmospheric Deposition on the Quality of Ground Water and Surface Water.

The sensitivity of lakes, streams, and soils to damage from acid rain depends on the nature of the soils and bedrocks. Watersheds containing limestone, which can buffer (partially neutralize) the acid, are less severely affected. In addition, northern regions with long winters suffer "acid shock" when spring thaws dump months of accumulated acid precipitation into streams and rivers. In the US, lakes and streams in the Appalachians, northern Minnesota and upper New York, and Western mountains have been more severely impacted by acid rain. According to the EPA, the pH of Little Echo Pond in New York state, 4.2, is one of the lowest in the U.S.

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** 14.9).

Figure 14.9: 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.

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

14.5 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.

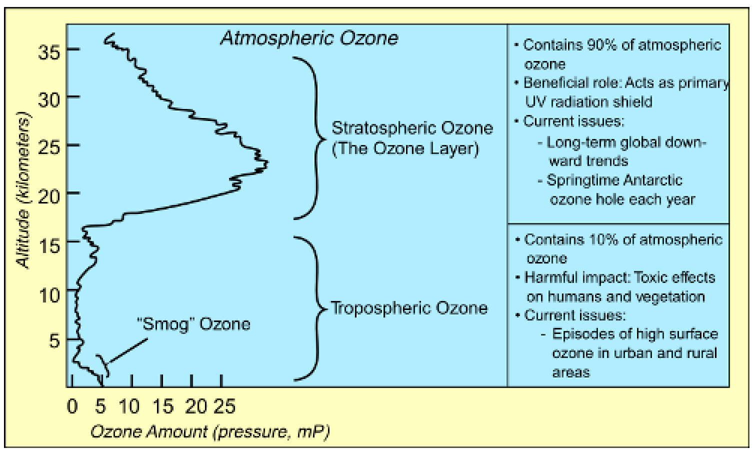


Figure 14.10: At altitudes less than 5 kilometers, respiratory irritant

Ozone is both a threat and a gift (**Figure** 14.11). 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 (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** 14.10).

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** 14.13). The second, much larger loss refers to the **ozone hole** – a seasonal decline over Antarctica (**Figures** 14.14 and 14), which has now lost as much as 70% of pre-1975 ozone

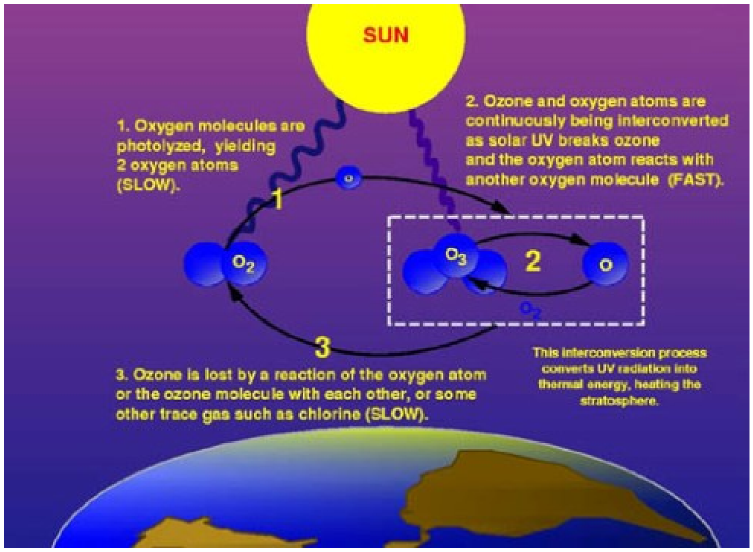


Figure 14.11: The ozone cycle involves the conversion of oxygen molecules to ozone (1 and 2) a slower reconversion of ozone molecules to oxygen (3). Interactions among ozone molecules or the presence of other reactive gases trigger the loss of ozone.

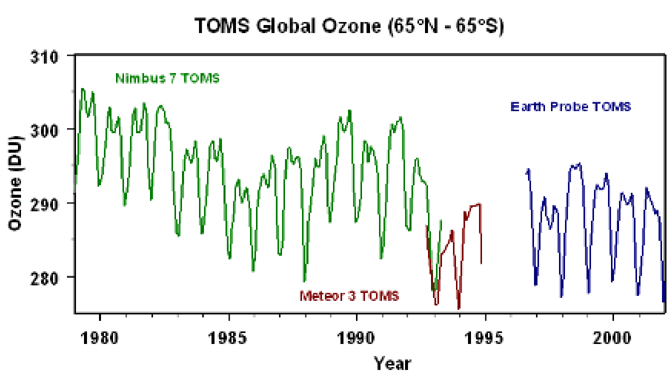


Figure 14.12: Total global monthly ozone levels measured by three successive spectrometers (TOMS) show both seasonal variations and a general decline.

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.

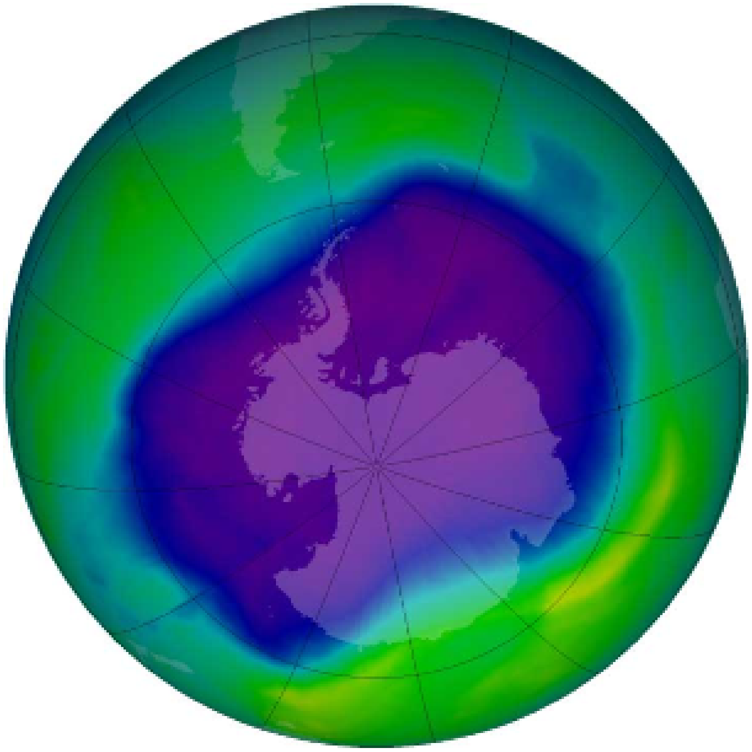


Figure 14.13: On September 24, 2006 the seasonal ozone hole over the Antarctic covered a record daily area (29.5 million square kilometres or 11.4 million square miles). Blue and purple areas show the lowest ozone levels, and green, yellow, and red indicate successively higher levels.

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

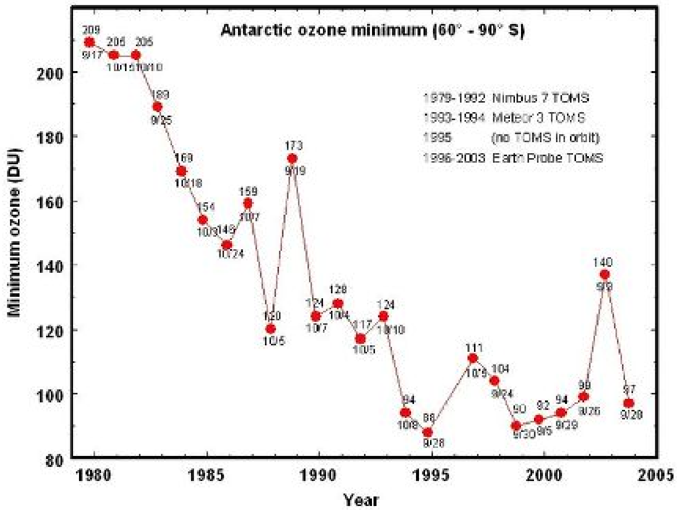
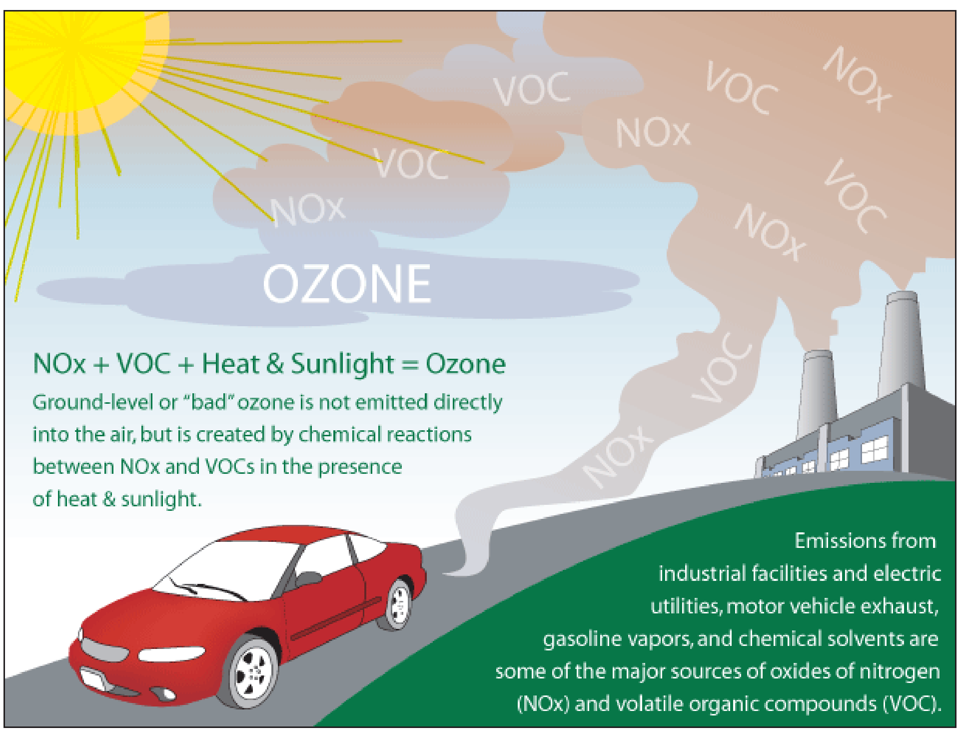


Figure 14.14: Lowest annual values of ozone in the ozone hole decreased dramatically between 1980 and 1995. Before 1980, values less than 200 Dobson units were rare, but in recent years, values near 100 units are common. Unusually high temperatures in the Antarctic stratosphere may have caused the high reading in 2002.

Table 14.28:



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** 14.12) 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

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** 14.13 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.

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

14.6 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.

Because fossil fuel use is the cause of so many atmospheric as well as water and soil pollutants, the solutions mentioned in the last two lessons apply here, as well. The final lesson on Climate Change relates directly to both fossil fuel combustion and atmospheric change, so more pollution solutions, specific to climate change, will be presented. You should also review the individual responses at the end of the lesson on **biodiversity**, because that list focuses on ways you can change your own life to help protect the environment.

14.7 End of Chapter Review & Resources

Chapter Summary

Earth's atmosphere, as we understand it today, provides ideal conditions and essential raw materials for life. Throughout Earth's history, the atmosphere has changed dramatically, and life caused some of the changes. Within human history, the atmosphere had been in a dynamic equilibrium: balancing photosynthesis, respiration, evaporation, and precipitation. Primary pollutants are directly added to the atmosphere by processes such as fires or combustion of fossil fuels. Secondary pollutants are formed when primary pollutants interact with sunlight, air, or each other. The majority of air pollutants can be traced to the burning of fossil fuels for heat, electricity, industry, transportation, and waste disposal. Worldwide, air pollution causes as many as 2.4 million deaths each year. Aerosols (particulates and liquid droplets) cab cause global dimming, or reduction in sunlight reaching the Earth. Light pollution can interfere with bird migrations, sea turtle reproduction, nocturnal animal behavior, and human activity. Rain, snow, fog, dew, and even dry particles which have an unusually low pH are commonly considered together as Acid Rain. Normal rain has a pH of about 5, due in part to formation of a weak (carbonic) acid from CO_2. Burning fossil fuels adds NO_x and SO_x gases to the atmosphere; these form strong acids (nitric and sulfuric) and change the pH of rain to as low as 2.4. Acid rain leaches nutrients and toxins from soils, weakening forests and killing aquatic animals. Limestone in bedrock or watersheds buffers the effects of acid rain for certain lakes. The development of taller smokestacks only sent pollution elsewhere, but scrubbers in smokestacks and catalytic converters in motor vehicles help to reduce emissions. The Ozone Layer in the stratosphere – formed from O_2 – protects Earth's life from mutagenic UV radiation. Ground-level ozone – formed from automobile exhaust and industry – is a component of smog, which irritates eyes and respiratory membranes. Ozone depletion is a global reduction in the thickness of the ozone layer, caused by chlorine and bromine atoms which reach the stratosphere. The ozone hole is a seasonal thinning of ozone above the Antarctic. CFCs in aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers are the primary ozone-depleting substances (ODSs). The 1987 Montreal Protocol has reduced the use of CFCs and ozone depletion. Chemical substitutes, though less harmful, still cause damage, and countries outside the Protocol may still add ODS to the atmosphere. Global warming would cool the stratosphere and increase ozone depletion, because cooler temperatures favor ozone decomposition. Because fossil fuels are the source of many air pollutants, reducing their use is the key to solving air pollution problems. Technology can help by developing alternative energy sources, increasing fuel efficiencies, and improving pollution control. Governments can help by legislating fuel efficiencies and pollution control, urban planning, and forging agreements with other governments.

Review Questions

1. Summarize the importance of the gaseous "life support system" which Earth's atmosphere provides, and the dynamic equilibrium which characterizes the natural atmosphere.
2. Explain the difference between the hole in the ozone and global warming (climate change)?
3. Describe the ecosystem services provided by Earth's atmosphere.
4. In what ways have we already begun to add the costs of atmospheric changes to our economic system?
5. What are the major ecosystem services provided by our atmosphere?
6. Distinguish between primary and secondary pollutants, and give an example of each.
7. Define acid rain and trace the steps in its formation.
8. Why is rain with a pH of 5 not considered acid rain?
9. Analyze the effects of acid rain on soils, water resources, vegetation, animals, and humans.
10. Define ozone depletion and explain its causes.
11. Explain the consequences of ozone depletion.Why are international treaties, such as the Montreal

Protocol and the Kyoto Treaty, so important in solving air pollution problems?

12. Chart the air pollution problems discussed in this chapter together with a primary cause and an important prevention practice for each.

Table 14.29:

Problem	Major Cause	Major Prevention Practice
Global Dimming		
Light Pollution		
Smog		
Acid Rain		
Ozone Depletion		

13.

Further Reading / Supplemental Links

- US Environmental Protection Agency, *Effects of Acid Rain - Surface Waters and Aquatic Animals,* ACID RAIN, US EPA website, last updated 8 June 2007. Available online at:
- http://www.epa.gov/acidrain/effects/surface_water.html
- http://www.epa.gov/highschool/air.htm
- http://www.anr.state.vt.us/site/html/reflect/April5.htm
- http://www.epa.gov/acidrain/
- http://www.atm.ch.cam.ac.uk/tour/
- http://www.epa.gov/ozone/
- http://www.pbs.org/wgbh/nova/sun/
- The University Center for Atmospheric Research web site provide detailed background information and the environmental effects associated with reduced ozone concentrations in the Polar Regions in the Antarctic and Arctic.
- More stratospheric ozone information can also be found at the EPA cite on ozone science and the science of ozone depletion.
- There is a nice virtual tour on the history of the discovery of the ozone hole provided by Cambridge University's Center of Atmospheric Science.
- Recent observations made at the British Antarctic Survey's Halley Research Station suggest that the 2003 ozone hole could be one of the biggest on record. There is a very nice animated graphic at bottom of their page on ozone status.(This is a 2.3 MByte file).
- The Goddard Space Flight Center and NASA monitor the ozone using the Total Ozone Mapping Spectrometer (TOMS). It too has nice animation and graphics comparing 2002 and 2003 ozone holes side-by-side from September 22 through October 6 for each year (click on the MPEG or Quicktime movies).
- A good review article article on acid rain in North America by Driscoll (2001) in BioScience. This is a 700kByte PDF file.
- For information on acid rain deposition check the acid rain web pages at the EPA. More information is at the National Atmospheric Deposition Program web pages.
- To understand how emissions trading works and how it has led to a reduction of acid rain in the US, read Clearing The Air: The Truth About Capping and Trading Emissions (a 0.6 MByte PDF file).
- The USGS has a site on acid rain with examples from Washington DC, especially the effects of acid precipitation on buildings. There is an active monitoring program in the US called the National Acid Precipitation Assessment Program (NAPAP) and they have a brief summary on their web site.

Environment Canada has also a very informative web page on acid rain (as well as other environmental issues including ozone hole over the Arctic Ocean).

- The EPA publishes Emission Reports listing the amounts of pollutants emitted by individual power plants.
- A European perspective with many good links can be found at the Swedish NGO Secretariat on Acid Rain.

Vocabulary to Know

- acid rain - Precipitation in any form which has an unusually low pH.
- aerosols - Airborne solid particles or liquid droplets.
- air pollution - Alteration of the Earth's atmosphere by chemical, particulate, or biological materials.
- algal bloom - A rapid increase in the growth of algae, often due to a similar increase in nutrients.
- anthropogenic sources - Sources of pollution related to human activities.
- biodiversity - Variation in life – at all levels of organization: genes, species, and ecosystems.
- ecosystem - A functional unit comprised of living things interacting with their nonliving environment.
- eutrophication - An increase in nutrient levels in a body of water, often followed by an increase in plant or algae production.
- global dimming - A reduction in the amount of radiation reaching the Earth's surface.
- global warming - The recent increase in the Earth's average near-surface and ocean temperatures.
- greenhouse effect - The trapping by the atmosphere of heat energy radiated from the Earth's surface.
- light pollution - Production of light by humans in amounts which are annoying, wasteful, or harmful.
- nonpoint source pollution - Runoff of nutrients, toxins, or wastes from agricultural, mining, construction, or developed lands.
- ozone depletion - Reduction in the stratospheric concentration of ozone molecules, which shield life from damaging ultraviolet radiation.
- ozone hole - A seasonal reduction in ozone levels over Antarctica.
- ozone layer - A concentration of ozone molecules located between 15 and 35 kilometers above Earth's surface in the stratosphere.
- point source pollution - Single site sources of nutrients, toxins, or waste, such as industrial or municipal effluent or sewer overflow.
- pollution - Release into the environment of chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life.
- primary pollutants - Substances released directly into the air by processes such as fire or combustion of fossil fuel.
- secondary pollutants - Substances formed when primary pollutants interact with sunlight, air, or each other.
- sustainable use - Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs.

References

DRISCOLL, C. T., G. B. LAWRENCE, et al. (2001). Acidic Deposition in the Northeastern United States: Sources and Inputs, Ecosystem Effects, and Management Strategies. BioScience 51(3): 180–198.

Krug, E. C. and C. R. Frink (1983). Acid Rain on Acid Soil: A New Perspective. Science 221 (4610): 520-525. Acid rain is widely believed to be responsible for acidifying soil and water in areas of North America and northern Europe. However, factors commonly considered to make landscapes susceptible to acidification by acid rain are the same factors long known to strongly acidify soils through the natural

processes of soil formation. Recovery from extreme and widespread careless land use has also occurred in regions undergoing acidification. There is evidence that acidification by acid rain is superimposed on long-term acidification induced by changes in land use and consequent vegetative succession. Thus, the interactions of acid rain, acid soil, and vegetation need to be carefully examined on a watershed basis in assessing benefits expected from proposed reductions in emissions of oxides of sulfur and nitrogen.

Rosenfeld, D., J. Dai, et al. (2007). Inverse Relations Between Amounts of Air Pollution and Orographic Precipitation. Science 315 (5817): 1396-1398. Particulate air pollution has been suggested as the cause of the recently observed decreasing trends of 10 to 25% in the ratio between hilly and upwind lowland precipitation, downwind of urban and industrial areas. We quantified the dependence of this ratio of the orographic-precipitation enhancement factor on the amounts of aerosols composed mostly of pollution in the free troposphere, based on measurements at Mt. Hua near Xi'an, in central China. The hilly precipitation can be decreased by 30 to 50% during hazy conditions, with visibility of less than 8 kilometers at the mountaintop. This trend shows the role of air pollution in the loss of significant water resources in hilly areas, which is a major problem in China and many other areas of the world

Chapter 15

Climate Change

15.1 Introduction

Oceans are important regulators of the climate. As air pollution and burning of fossil fuels increase more evidence of climate change, melting ice caps, and other related environmental issues are occuring.

Chapter Objectives

- Understand how the oceans regular climate.
- Define and describe what climate is.
- List the green house gasses.
- Give examples of how natural and human activity are changing the greenhouse gas compositions.
- Describe what the green house effect is.
- List the different lines of evidence supporting climate change.
- Explain the mechanism of the greenhouse effect.
- Recognize that the greenhouse effect maintains an equilibrium.
- Compare greenhouse conditions on Earth to those on Mars and Venus.
- Explain the extent of current increases in the Earth's temperature.
- Review past changes in the Earth's temperatures.
- Summarize the evidence and support for greenhouse gases as the cause of recent global warming.
- Discuss the significance of global warming for Earth's ecosystems.
- Relate global warming to current global stability.
- List the atmospheric gases that absorb the Earth's thermal radiation, and their sources.
- Evaluate possible solutions to the problem of global climate change.
- Recognize the tradeoffs required by nuclear power plants: reduced emissions vs. radioactive fuels and waste

15.2 The Ocean and Climate

We are not merely inhabitants of a planet, adapting ourselves to it. Life has verily constructed the planet. It would not behave as it does, even in its deep interior, were it not for life. [Most of that life was in the ocean.] (Oldroyd 1996: 297)

To understand climate change, we must first review what climate is again, and then look at how oceans regulate the climate.

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 and Ocean Life Strongly Influenced Earth's Climate Over Billions of Years

Earth is totally different from what it would be if it had no ocean. The ocean, and life in the ocean, have "constructed the planet." The ocean is an important part of the Earth System, and it influences the transformation of energy and materials important to the climate system. On the most basic level, the ocean has shaped our atmosphere. Over millions of years, the concentration of gases in the atmosphere is determined by life. If life did not exist, especially life in the ocean, earth would be very different. On a deeper level, oceanic microbes irreversibly altered the geochemistry of earth and the biogeochemical cycles of H, C, N, O and S.

Please note, there is only one ocean with many named parts. The largest parts are the Atlantic, Indian, and Pacific Oceans. Earth would be much different if there were several different, disconnected oceans.

> The evolution of photosynthesis remade the Archaean Earth. Before photosynthesis, the air and oceans were anoxic. Now the air is a biological construction, a fifth of which is free molecular oxygen, and the ocean can sustain animal life even in the depths. The evolution, first of anoxygenic [not producing oxygen] and then of oxygenic [producing oxygen] photosynthesis, sharply increased the productivity of the biosphere. Oxygenic photosynthesis sustains free oxygen in the atmosphere. In the oceans, the beneficiaries of the first photosynthetic prokaryotes [bacteria and archaea] today range from cyanobacterial and algal plankton to large kelp. Wearing plants as landsuits, from tiny mosses to giant redwoods, cyanobacteria as chloroplasts have occupied the land. The oxygen emitted has allowed the evolution of animal life, to browse the plants and, in turn, to respire the CO_2 that sustains photosynthesis. The management of the carbon cycle, by photosynthesis coupled with respiration, had profound consequences for the greenhouse setting of the surface temperature. Photosynthetic productivity controls the budgets of atmospheric carbon dioxide and, eventually, methane too. This sets global temperatures, weather patterns and may have even been a cause of the great glacial events, where much of the Earth's surface froze over. Bendall et al (2008).

1. Carbon dioxide, the most common gas on Venus is rare in earth's atmosphere because oceanic animals have used carbon dioxide to make vast layers of carbonates in the form of limestone, dolomite, and marble. Without life, our atmosphere would be similar to that of Venus. Most sedimentary rocks were laid down in the ocean.

El Capitan, Capitan Reef, Guadalupe Mountains National Park, Texas. This is a coral reef is from the Permian. Photograph by Mark Eberle, November 1999. From: Natural History of the Southwestern United States, a Fort Hayes State University course taught by Mark Eberle.

Free oxygen O_2 which is not found in the atmosphere of other planets, is produced by life. It is found in the atmosphere because of production by photosynthesis and the deposition of organic carbon on the the sea floor and the eventual inclusion of the organic carbon into continental rocks by plate tectonics acting over many millions of years (Falkowski and Godfrey, 2008). The organic carbon is stored in sedimentary rocks on continents in the form of oil shales, coal, oil, and natural gas.

Oxygen in the atmosphere led to the formation of earth's stratospheric ozone layer which protects all life from solar ultraviolet radiation.

The Ocean Strongly Influence Earth's Present Climate

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

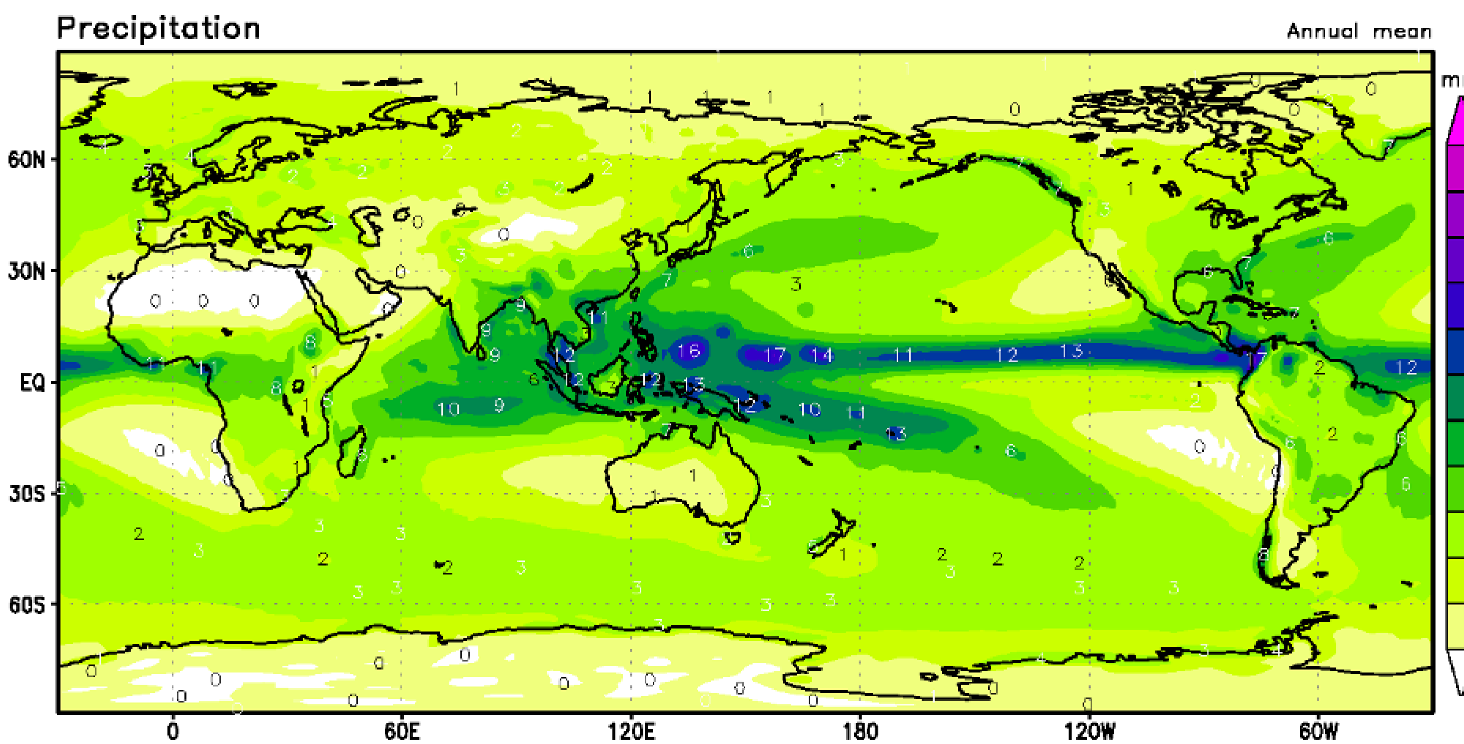
1. Most of the sunlight absorbed by earth is absorbed at the top of the tropical ocean. The atmosphere does not absorb much sunlight. It is too transparent. Think of a cold, sunny, winter day at your school. All day long, the sun shines on the outside, but the air stays cold. But if you wear a black 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 ECMWF 40-year reanalysis of atmospheric data. Notice that most of the heat absorbed by earth goes into the tropical ocean. From Kallberg et al 2005.

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).

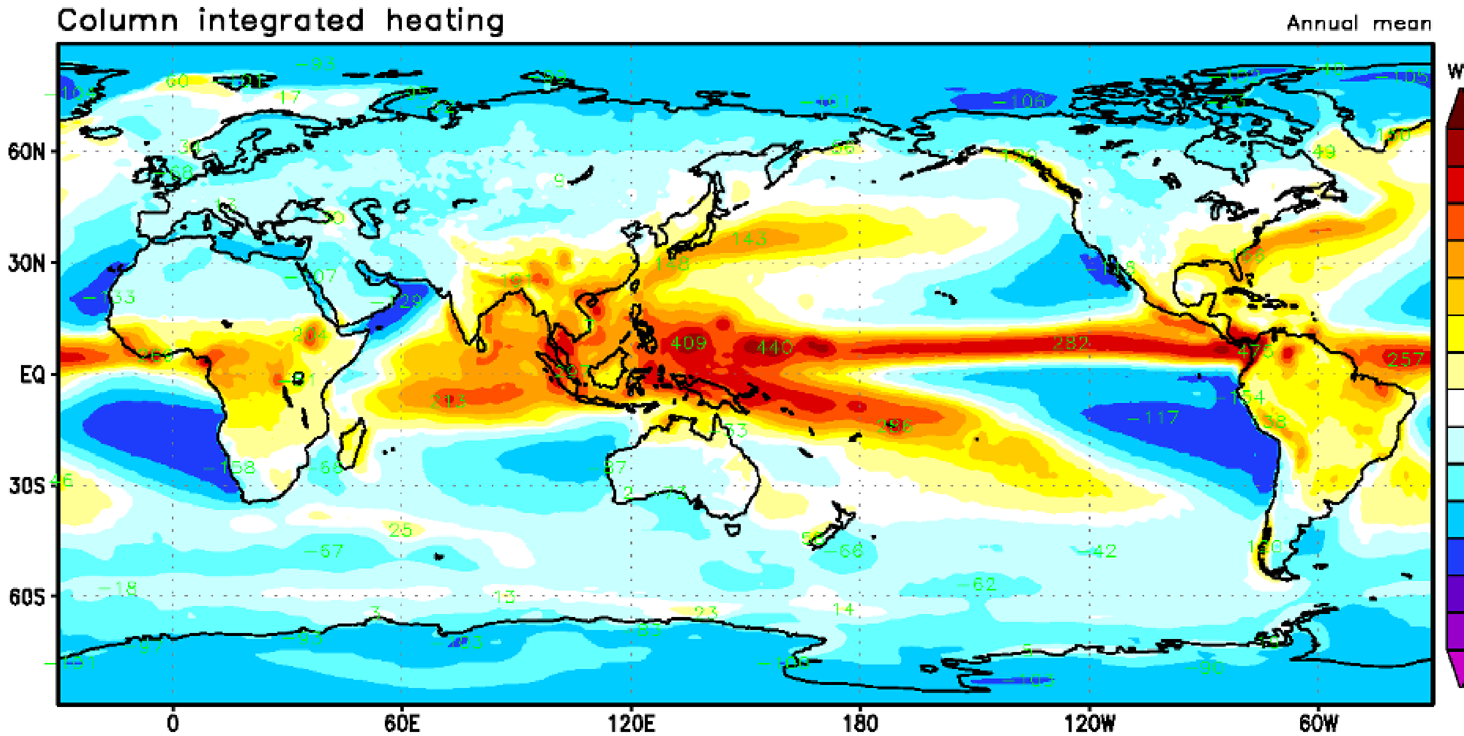
1. So much heat is released by rain in the Inter-Tropical Convergence Zone that it drives much of the atmospheric circulation. This circulation is called the Hadley circulation.
2. Heat released by rain in higher latitudes drives storms and winds.
3. Heat released by rain in hurricanes and thunderstorms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

Table 15.5:

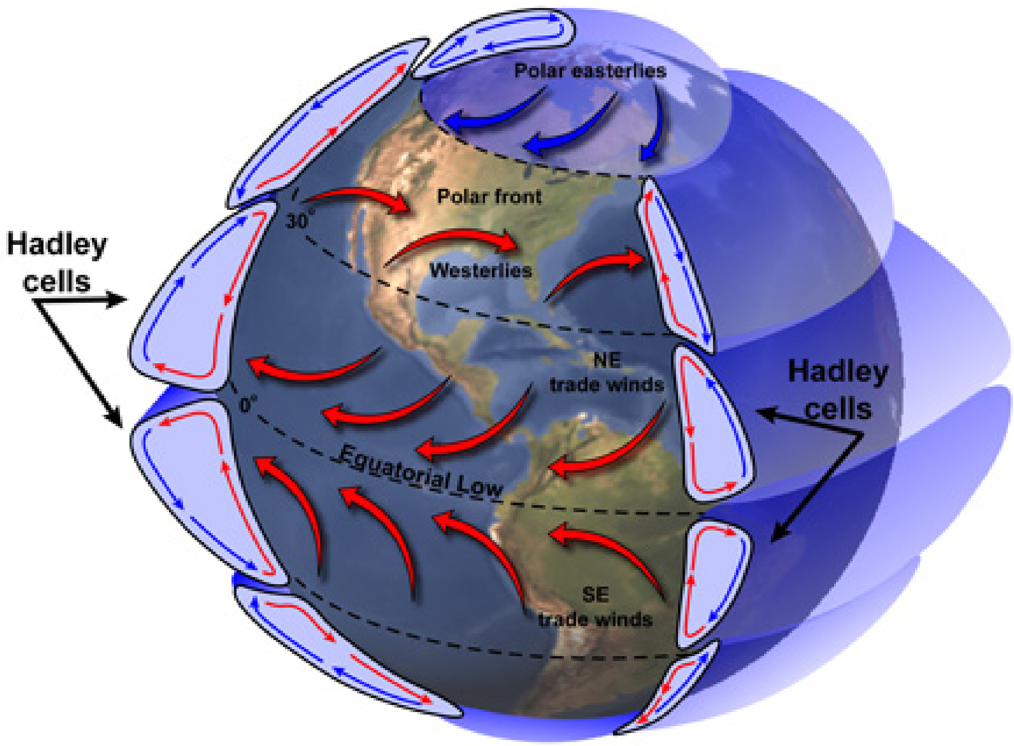


25-year average of rain rate. From Japan Meteorological Agency, Japanese 25-year Reanalysis (JRA-25) Atlas.

Table 15.6:



25-year average of heating of the atmosphere. Notice the high correlation with rain rate shown above. Rain and absorption of infrared radiation heats the atmosphere, mostly in the tropics. This heating drives the atmospheric circulation. From Japan Meteorological Agency, Japanese 25-year Reanalysis (JRA-25) Atlas.



Upper: Rain in the tropics warms the atmosphere and drives the Hadley circulation. Image from The Why Files.

Bottom: The Hadley cells (circulation) are a major part of the climate system. Click on image for a zoom. Image from NASA Earth Observatory,Fewer Clouds Found In Tropics.

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

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.

The winds drive ocean currents, and together they carry heat from the tropics to the polar regions. See The Climate System below.

The ocean dominates earth's hydrological cycle.

1. All but 3% of earth's water is in the ocean. See The Hydrological Cycle.
2. The ocean supplies almost all the water that falls on land. Watch moisture stream from the tropics into mid-latitudes where it falls as rain in thisvisualization for January and for August from theVisualization Group at the National Center for Atmospheric Research.

The ocean and ocean life control the amount of carbon dioxide in the atmosphere, and they dominate earth's carbon cycle.

Carbon dioxide is a greenhouse gas. By absorbing infrared radiation (energy) from the earth's surface, it helps keep the surface warm. The amount of carbon dioxide in the air is increasing, partly because we burn fossil fuels such as coal, natural gas, and oil. The increasing amounts of carbon dioxide are causing earth to slowly warm up. To understand the warming, we must understand how the ocean controls earth's carbon cycle.

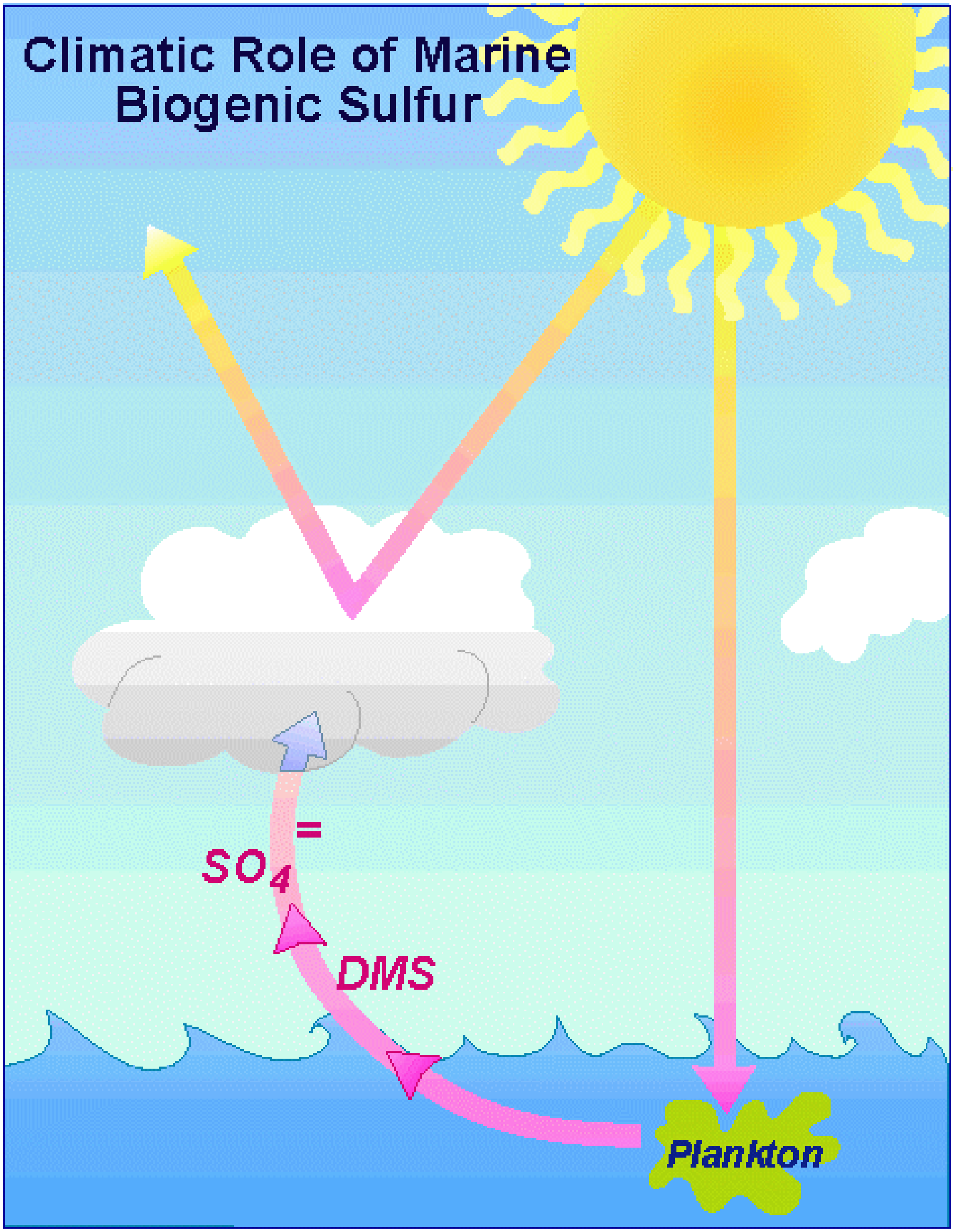
1. Most of the available carbon is in the ocean. The ocean holds 50 times more carbon than the atmosphere.
2. About half of earth's primary production, the conversion of water, carbon dioxide, sunlight, and inorganic nutrients into oxygen and hydrocarbons, occurs in the ocean. Primary producers in the ocean are the phytoplankton. They also produce oxygen as a by product of this reaction.
   (a) When the phytoplankton die and decay, or when they are eaten, the hydrocarbons are converted back to carbon dioxide, using up all the oxygen produced by the phytoplankton.
   (b) But, sometimes phytoplankton and other life in the sea die and sink to the sea floor before they can decay. When they are buried in the sediments, they leave behind the oxygen produced by the phytoplankton. Over millions of years this produced the oxygen in the atmosphere. It also produced the oil, gas, and coal we now use to make electricity, heat our homes, and run our cars and trucks. We call this process the biological pump that takes carbon dioxide out of the air.
3. Almost exactly half of the carbon dioxide put into the air by our burning of fossil fuels is absorbed by the ocean. Carbon dioxide dissolves in cold water near the Arctic and Antarctic. When the cold water sinks deep into the ocean in winter, it carries the carbon dioxide away from the atmosphere. Many years later, the water is gradually pulled closer to the sea surface by mixing in the ocean. When it gets to the surface in warm areas it releases the carbon dioxide back to the air. This process allows the ocean to store great quantities of carbon dioxide for many centuries. We call this the physical pump that takes carbon dioxide out of the air.
4. The biosphere expands and contracts on a 450,000 year cycle in response to changes in insolation (incoming sunlight at different latitudes). The long period is due to long-term storage of carbon in the ocean and the dissolving of carbonate on the sea floor. Palike (2006).

Phytoplankton strongly influence cloud formation and climate.

Clouds influence the reflection sunlight from earth, which influences earth's temperature (Meskhidze and Nenes (2006). The phytoplankton release great quantities of a sulfurous gas called dimethyl sulfide which changes the way clouds are formed in the atmosphere. First, sunlight causes chemical reactions that change the gas to sulfate aerosols (microscopic particles in the air). The tiny aerosol particles cause water vapor to condense to form cloud drops. Because about one-third of the sunlight reaching earth is reflected back to space by clouds, any process that influences cloudiness also influences the amount of sunlight that is absorbed by earth.

Table 15.9:

Phyto-



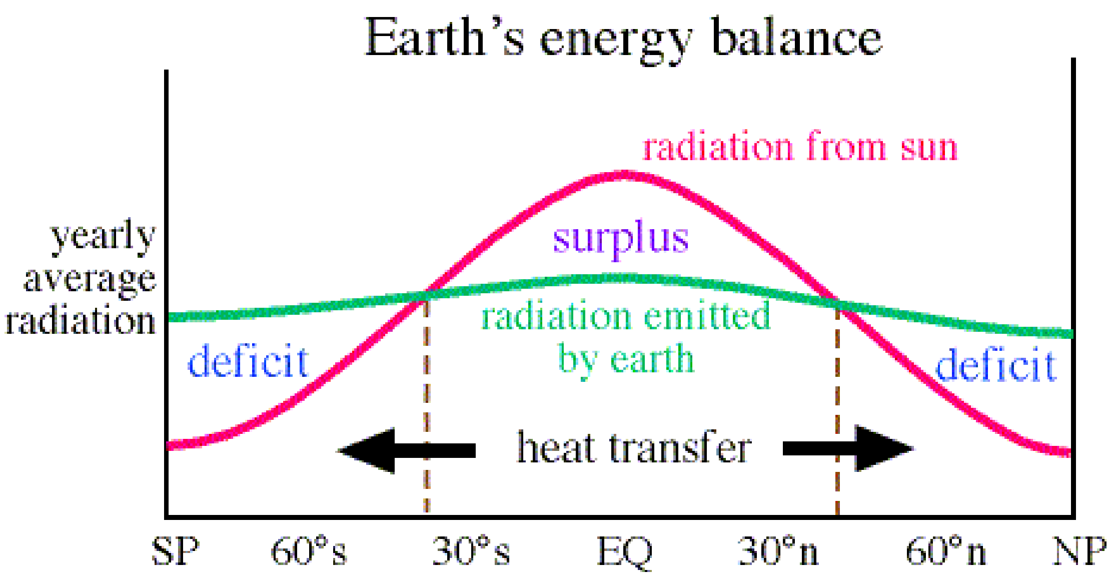
plankton in the ocean produce dimethyl sulfide (DMS) that is converted to sulfate aerosols (SO_4), which influence the amount of sunlight reflected by clouds. From Oceanic Dimethyl sulfide (DMS) and Climate by the Atmospheric Chemistry Program at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory.

The ocean stores and transports heat.

Temperature in the atmosphere, even global changes in temperature are slowed by the exchange of heat with the ocean. Thus, 18 times more heat has been stored in the ocean since the mid 1950s due to global warming than has been stored in the atmosphere. Most of the heat trapped by greenhouse gases has gone into the ocean, not the atmosphere. Earth's climate is the result of the uneven distribution of the temperature at the surface. The difference in temperature between the poles and the tropics eventually leads to winds and ocean currents that carry heat heat from the tropics to the polar regions. The ocean carries heat out of the tropics, and the winds carry heat to higher latitudes.

1. The tropics are warm because they receive so much sunlight.
2. The poles are cold because they receive much less sunlight, and because the polar atmosphere is transparent to infrared radiation. They radiate away much more heat than they receive from the sun.

Table 15.10:

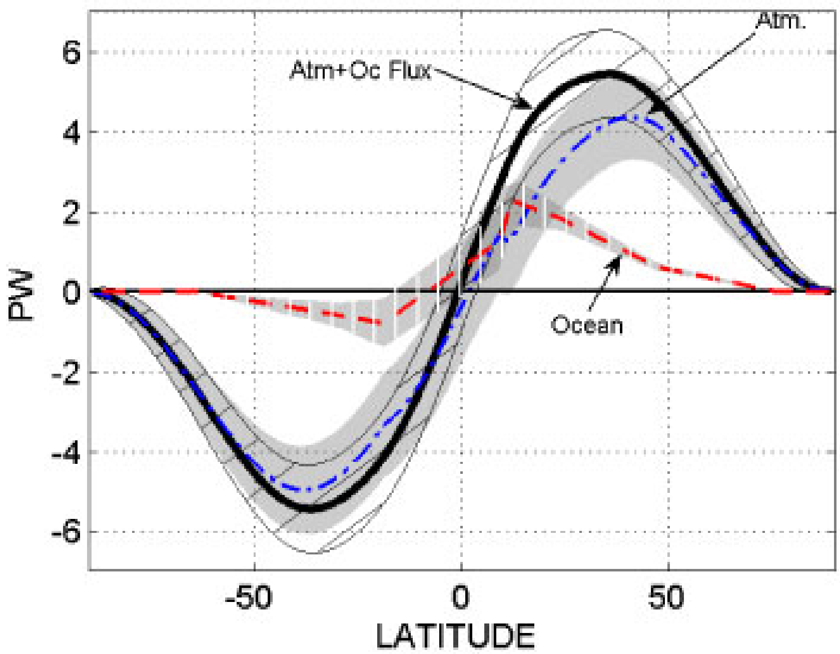
	Zonal av-

erage of heat gained from the sun (red line) and lost to space by emitted infrared radiation (green line). Image from Lyndon State CollegeSurvey course by Nolan Atkins.

Table 15.11:

Table 15.11: (continued)

This plot shows the



zonal average of heat transported by the atmosphere and the ocean in units of petawatts (PW = 10^{15} Watts) (solid black line), by the ocean (red dashed line), and by the atmosphere (blue dashed line), averaged along lines of constant latitude. The ocean is important for carrying heat out of the tropics, and the atmosphere is important at latitudes greater than 20°. From Wunsch (2005). The Total Meridional Heat Flux and Its Oceanic –2380.

3. The transport of heat is influenced by many other parts of the earth system.
   (a) Continents interrupt or deflect winds and currents.
   (b) Life on earth has changed the composition of the atmosphere, which has changed the way heat gets from earth's surface to space.
   (c) Water vapor in the atmosphere also influences the way heat gets from earth's surface to space. Water vapor is the most important greenhouse gas.
   (d) Water evaporated from the ocean carries heat into the atmosphere, and it warms the atmosphere when it condenses as precipitation. Most of the heating occurs in the tropical rain belts.

Variations in the ocean's circulation have been implicated in abrupt climate change during the last 400,000 years.

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 summer due to the North American monsoon. Click on the image for a zoom. From the National Weather Service Forecast Office Flagstaff Arizona's article on the monsoon.

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.

Influence of Greenhouse Gases Especially Water Vapor

Let's look at how greenhouse gases influence the climate system, and how they might cause climate change. The ideas below come from George Philander's book, Our Affair With El Niño, chapter 7: Constructing a Model of Earth's Climate, page 105.

1. Earth with no atmosphere If earth had no atmosphere, if it had a land surface that reflected some sunlight like the real earth, and if it were in equilibrium with solar heating, the average surface temperature of earth would be -18°C (0°F), far colder than the average temperature of our earth, which is 15°C (59°F). Worse, the surface would cool down to around -160°C (-250°F) soon after the sun set because the surface would radiate heat to space very quickly, just as the moon's surface cools rapidly as soon as the sun sets on the moon.
2. Earth with a static atmosphere and no ocean If the earth had a static atmosphere with the same gases it has now, but with little water vapor and no ocean, the average surface temperature of earth would be 67°C (153°F). This is much warmer than our earth. The planet would be so hot because greenhouse gases in the atmosphere help keep heat near the surface, and because there is no convection, and no transport of heat by winds. Adding winds cools the planet a little, but not enough.
3. Earth with an atmosphere and ocean Earth has an atmosphere and ocean, and the average surface temperature is a comfortable 15°C (59°F). Water evaporates from the ocean and land, cooling the surface. Winds carry the water vapor to other latitudes, and sometimes high up into the air, where heat is released when the vapor condenses to water.

Table 15.14:

This very large thunderstorm was photographed by astronauts flying over the Indian Ocean, east of Madagascar (25.0N, 56.0E). The storm is about 65 nautical miles on a side and has a top that reaches into the stratosphere at 45,000 to 50,000 ft. and casts long shadows in the low sun. Such storms carry heat from the tropical seas high into the atmosphere, cooling the surface. Image fromCamex-4 Program, NASA Marshall Space Flight Center. Original from NASA Johnson Space Center.

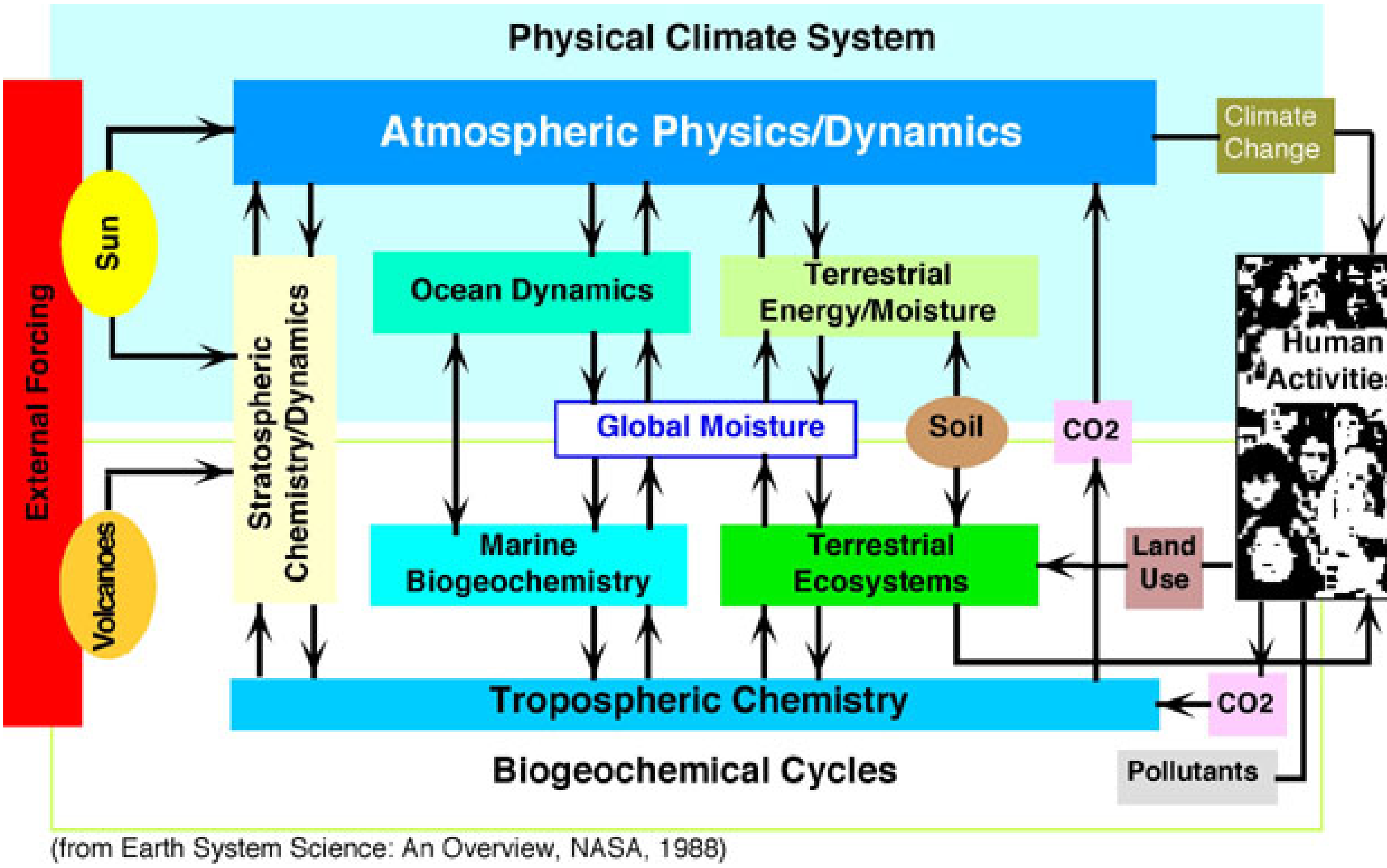
http://oceanworld.tamu.edu/resources/oceanography-book/Images/10064673_m.jpg

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.

Table 15.15:



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).

Conversion factors for temperature

1. 0 degrees Celsius = 273.15 Kelvin
2. Degrees Fahrenheit = 9/5 Celsius + 32

3. So, zero degrees Celsius = 32 degrees Fahrenheit

15.3 The Carbon Dioxide (CO_2) 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.

NOAA)

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.

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:

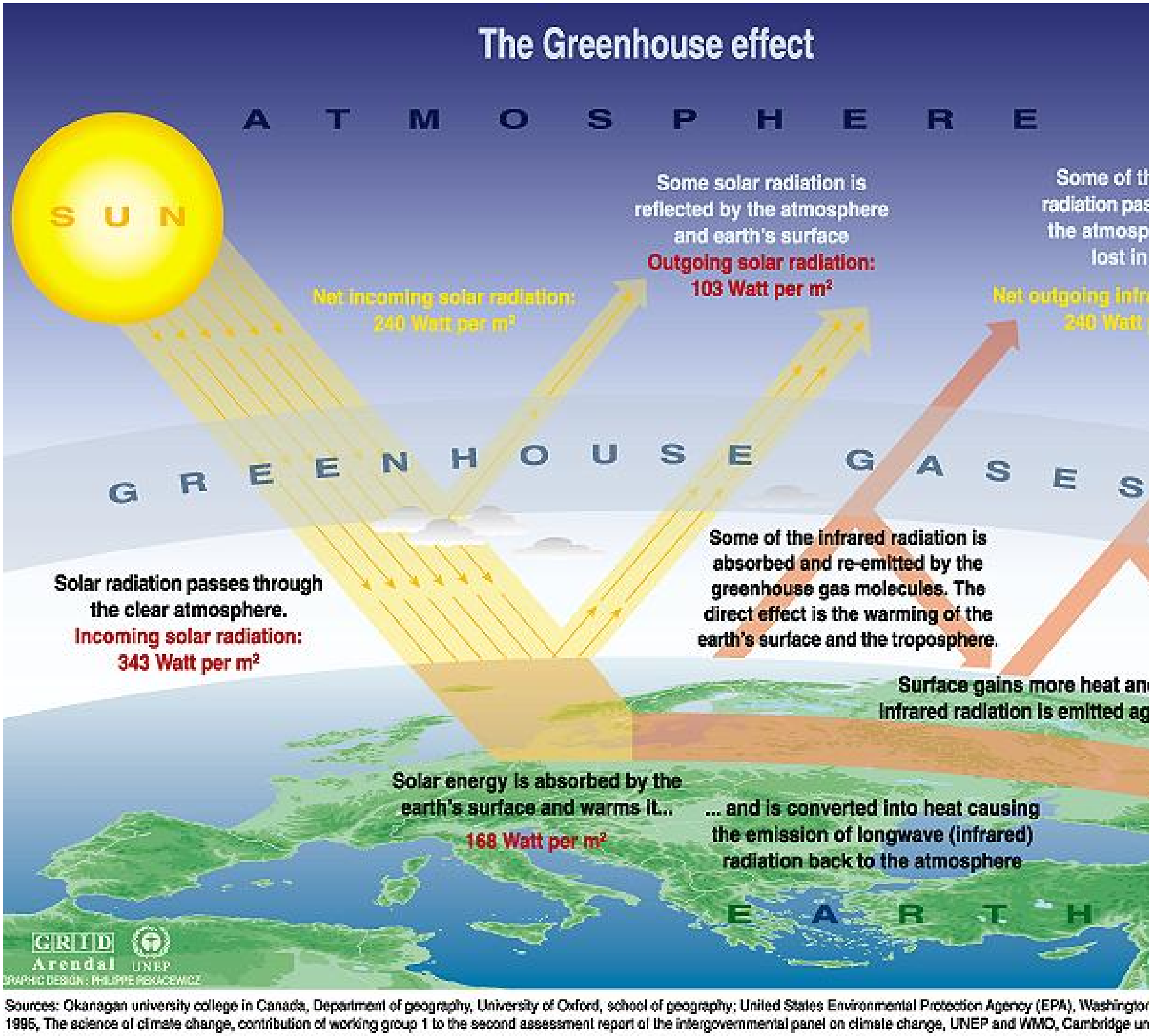
1. Water vapor. This is by far the most important greenhouse gas. It evaporates mostly from the ocean, and it causes earth's surface to be about 30°C warmer (out of the 33°C of warming caused by all greenhouse gases combined). See Ocean and Climate for a discussion of how much water warms the atmosphere.
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.

15.4 Earth's Radiant Energy Balance and Oceanic Heat Fluxes

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.

Table 15.19:



The greenhouse effect. From the Introduction to Climate Change written by the United Nations Environmental Program's UNEP Global Resources Information Database (GRID) office in Arendal Norway.

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

How does the greenhouse effect work? View the BBC animation illustrating the Greenhouse Effect.

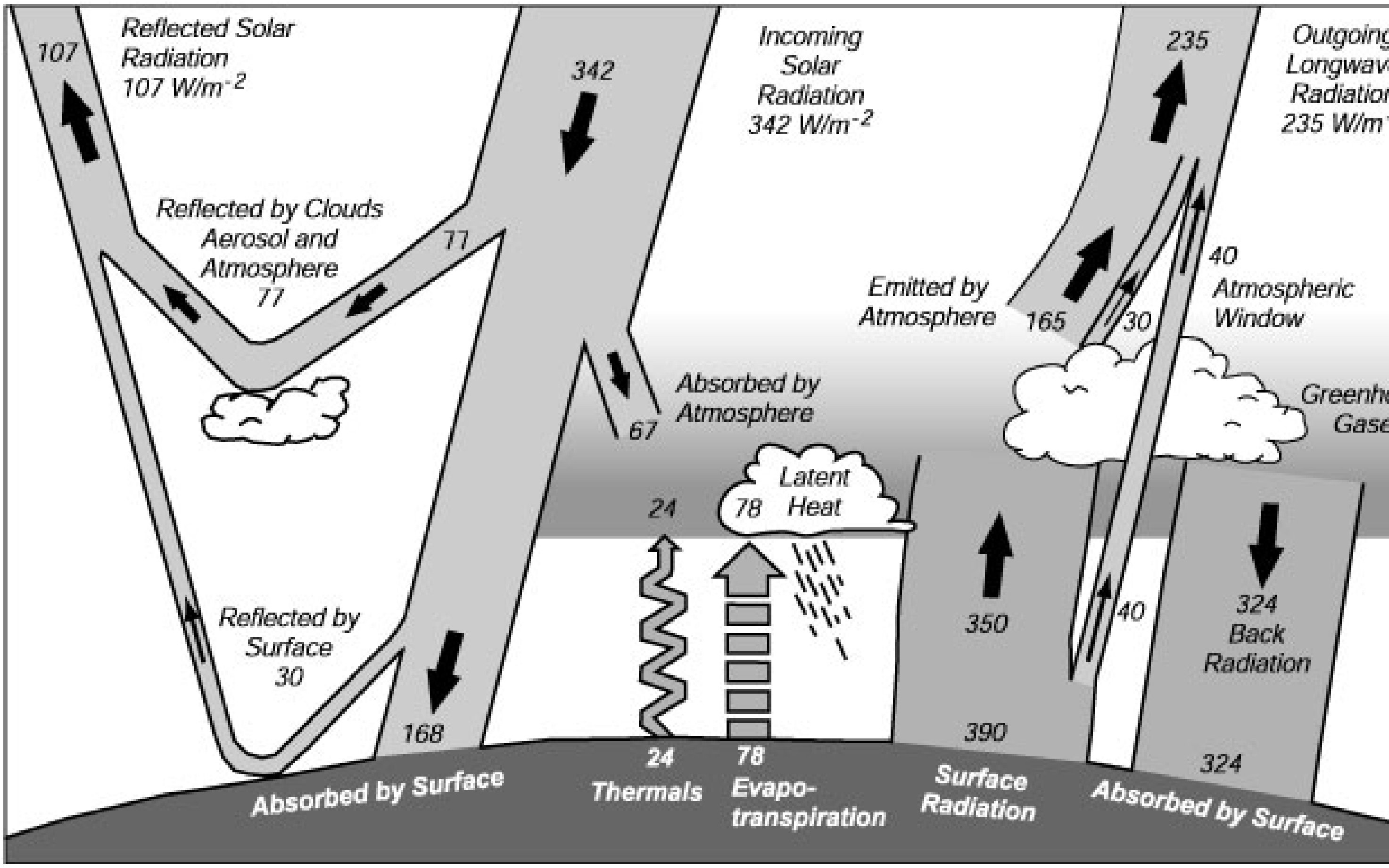
The basic idea is: the atmosphere is transparent to solar radiation. It allows sunlight to reach and warm the earth's surface. The atmosphere is mostly opague to infrared radiation emitted from earth's surface, hindering the emission of radiation from the surface to space, keeping the surface warm.

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.
6. The surface cools primarily in two ways:
   (a) All surfaces radiate heat, mostly at wavelengths close to 10 µm wavelength. On average, they radiate 390 W/m^2. This is more than the incoming solar heat, and earth would rapidly cool if there were no greenhouse gases.
      i. 90% of the infrared energy emitted by the surface is absorbed by greenhouse gases in the atmosphere.
      ii. 10% of the infrared energy emitted by the surface goes directly to space, mostly in polar regions.
   (b) The ocean evaporates, losing latent heat. On average, two meters of water is evaporated from the tropical ocean each year. In addition, small amounts of water evaporate from land and plants on land. On average 78 W/m^2 is lost by evaporation. All latent heat is released in the atmosphere when the evaporated water condenses as water in clouds and rain. This warms the atmosphere.
7. The atmosphere cools by radiating infrared energy to space.
8. 45% of the heat that warms the atmosphere is radiated to space (235 W/m^2).
9. 55% of the heat that warms the atmosphere is quickly re-radiated radiated back to the earth (324 W/m^2). This warms the earth and the lower 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.

Table 15.20:



The mean annual radiant energy and heat balance of the Earth. From Houghton et al., (1996: 58), which used data from Kiehl and Trenberth (1996).

Please note the special use of words. Sunlight is reflected by surfaces and absorbed by gases and surfaces. Greenhouse gases do not reflect sunlight. Infrared energy is emitted and absorbed by surfaces and greenhouse gases. Radiation refers to radiant energy, not nuclear radiation.

Notice also that the amount of infrared energy emitted at the top of the atmosphere (235 W/m^2) must equal almost exactly the amount of solar energy absorbed by earth (342 – 107 W/m^2). The small difference, about a watt per square meter, leads to global warming or cooling.

Greenhouse Gases

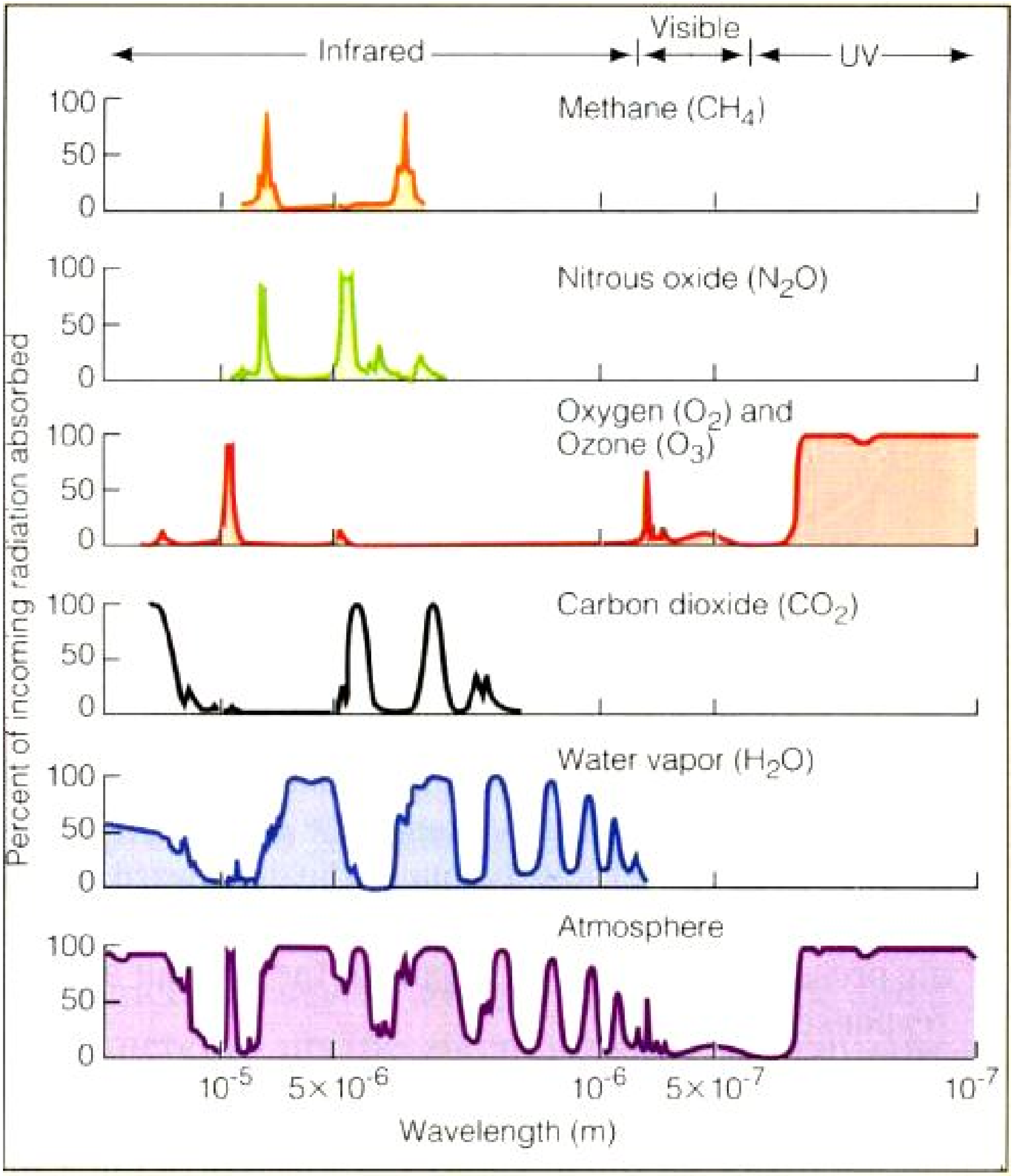
Greenhouse gases are composed of molecules with three or more atoms that absorb infrared energy but not visible light. There are four important greenhouse gases, and several less important gases. This animation, from the University Corporation for Atmospheric Research shows a tri-atomic, CO_2 molecule absorbing and re-emitting a photon of infrared energy. Remember, molecules can absorb or emit only photons with precisely the right amount of energy, and energy is inversely proportional to wavelength.

See the animated image of molecule absorbing and emitting radiation. Absorption of an infrared photon increases the energy of the molecule, shown here as a vibration of the position of the oxygen atoms relative to the carbon atom in the molecule. The molecules emits a photon of exactly the same energy that it absorbed, and stops vibrating. From UCAR web page on the greenhouse effect.

1. Water vapor H_2O is by far the most important greenhouse gas. It accounts for about 30°C of the 36°C increase in earth's surface temperature due to the combined influence of all greenhouse gasses.
2. Carbon dioxide CO_2 is the second most important greenhouse gas. Its lifetime in the atmosphere hard to determine, but is in the range of 5 to 100 years.
3. Methane CH_4. Methane is a reactive trace gas (lifetime 10 yr) that plays key roles in Earth's climate and atmospheric chemistry. Its infrared activity currently accounts for 12% of enhanced greenhouse forcing, and it participates in tropospheric O_3 and OH regulation and in the stratospheric H_2O cycle. Tropospheric CH_4 has more than doubled during the past 200 yr and the current tropospheric rate of increase is both significant and variable, reflecting varying source-sink strengths (Naqvi, 2005).
4. Nitrous oxides N_2O. Unlike CH_4, the atmospheric budget of N_2O is greatly influenced by its production in the ocean and exchange across the air–sea interface, since the oceans are estimated to account for at least one-third (4.7–6.3 Tg N_2O y^1) of N_2O inputs to the atmosphere from all natural sources (15 Tg N_2O y^1) (Naqvi, 2005).
5. Less important gases are tropospheric ozone O_3 and a number of substances containing fluorine, among them HFCs (compounds of hydrogen, fluorine and carbon).

The net effect of gases in the atmosphere is to allow sunlight in, and to hinder the transfer of heat from the surface to space. Absorption of radiant energy by atmospheric gases is a function of wavelength, and this is important to understanding how different molecules trap radiant energy.

Table 15.21:

 This plot shows the transparency of the atmosphere as a function of wavelength (bottom) and the influence of absorption by different atmospheric gases. Between 0.6 µm and 0.3 µm the atmosphere is clear (an atmospheric window) allowing sunlight to reach the surface. There is a less clear window near 10 µm that allows infrared energy to carry heat from the surface to space. Greenhouse gases partly obstruct the clarity of the window, helping keep the surface warm. Note that water vapor is highly variable, absorbing infrared energy much more strongly in the tropics and much less in the polar regions. Aplot of absorption for various regions by Selby and McClatchey shows the influence of water vapor much more clearly. Plot from fromGEOG-1425 class notes, Katherine Kink, University of Minnesota.

The Role of Water and Water Vapor in the Earth System

The influence of greenhouse gases is only part of the process. If the earth were in radiative equilibrium, with an atmosphere, the surface temperature would be 67 degrees C. This does not happen because water evaporates from the surface, mostly from tropical seas, cooling the surface (Philander, 1998: 78).

> The simple picture of the greenhouse mechanism is seriously oversimplified. Many of us were taught in elementary school that heat is transported by radiation, convection, and conduction. The above representation [of the simple greenhouse effect] only refers to radiative transfer. As it turns out, if there were only radiative heat transfer, the greenhouse effect would warm the Earth to about seventy-seven degrees centigrade rather than to fifteen degrees centigrade. In fact, the greenhouse effect is only about 25 percent of what it would be in a pure radiative situation. The reason for this is the presence of convection (heat transport by air motions), which bypasses much of the radiative absorption ... The surface of the Earth is cooled in large measure by air currents (in various forms including deep clouds) that carry heat upward and poleward. One consequence of this picture is that it is the greenhouse gases well above the Earth's surface that are of primary importance in determining the temperature of the Earth. That is especially important for water vapor, whose density decreases by about a factor of 1,000 between the surface and ten kilometers above the surface. Another consequence is that one cannot even calculate the temperature of the Earth without models that accurately reproduce the motions of the atmosphere. Indeed, present models have large errors here–on the order of 50 percent. Not surprisingly, those models are unable to calculate correctly either the present average temperature of the Earth or the temperature ranges from the equator to the poles. Rather, the models are adjusted or "tuned" to get those quantities approximately right. Richard S. Lindzen, Former Alfred P. Sloan Professor of Meteorology at the Massachusetts Institute of Technology.

To understand earth's temperature, we must also understand the role of water, water vapor, and ice in the earth system.

1. The most important greenhouse gas is water vapor.
2. It evaporates, mostly by the tropical ocean, in response to heating by the sun. Sunlight warms the ocean's surface, which cools by evaporation. In simple terms, the ocean sweats to keep cool. The water vapor then continues through the Earth's hydrological cycle.
3. Some is carried into the Intertropical Convergence Zone (ITCZ) where it rises, condenses into rain, and releases the stored solar energy. Rain releases latent heat. This heats the air, drives the convection in the ITCZ, and it is the major heat source for driving the atmospheric circulation.
4. The atmospheric circulation carries heat poleward, reducing the temperature contrast between poles and tropics.
5. The circulation also carries water vapor high into the atmosphere, allowing it to radiate heat efficiently to space.
6. Some condenses into puffy clouds. These clouds, and the convective clouds in the ITCZ reflect sunlight leading to a cooler earth.
7. Some remains in the air and absorbs infrared energy emitted by earth. This increases the greenhouse effect leading to a warmer earth.

A major cause of concern is the relative importance of water in clouds and as vapor. Is the cooling by clouds more or less important than the warming by vapor? Water vapor and cloud drops can warm or cool earth's surface through feedback loops.

Aerosols

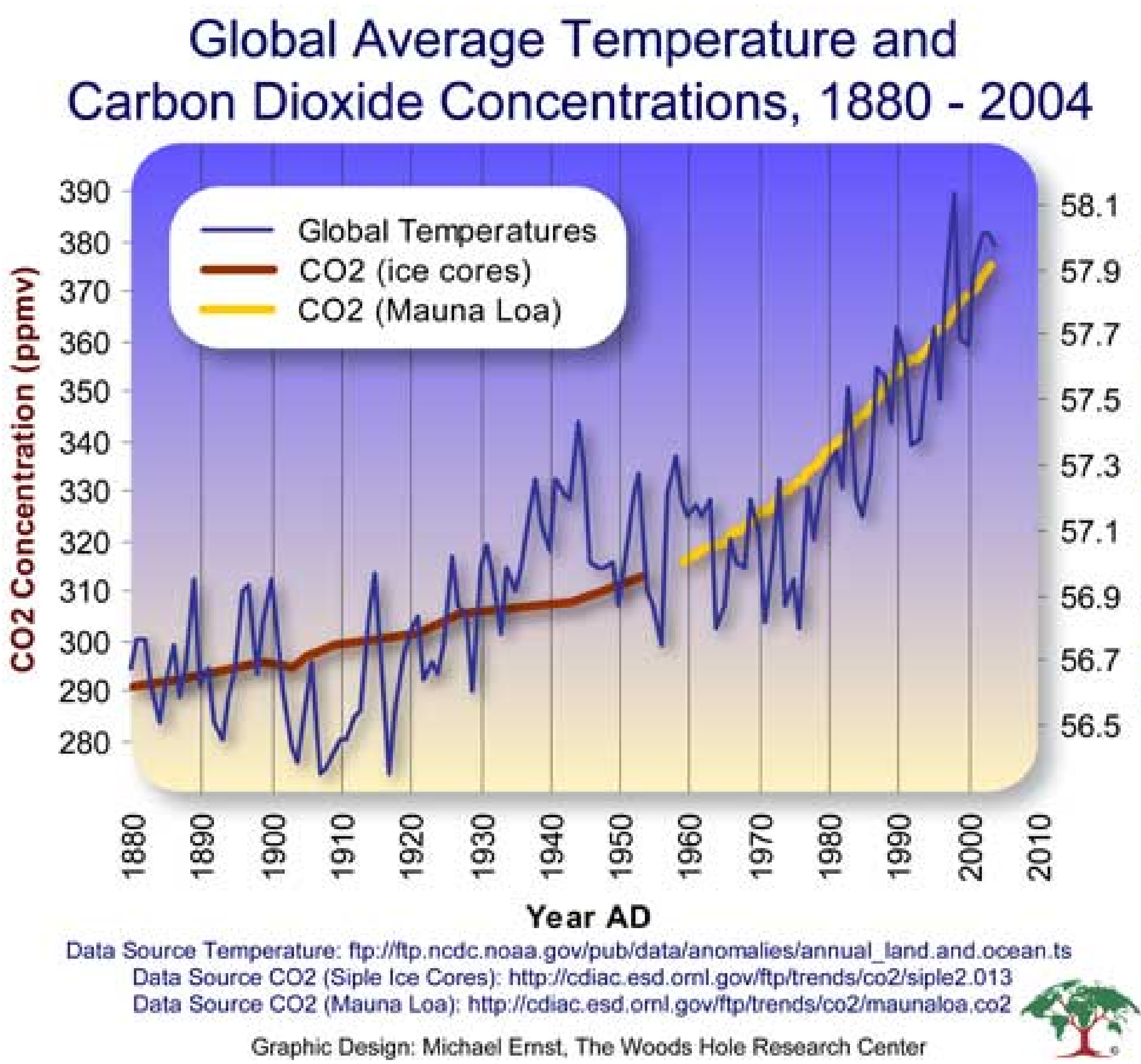
Small, microscopic, liquid or solid particles in the air (not the gas in aerosol cans), called aerosols, also influence earth's radiant energy balance. Aerosols reflect and absorb solar and infrared energy. Yet their importance is not well known.

Aerosols include:

1. The water droplets that make up clouds.
2. Soot (carbon particles) from forest fires and the burning of fields and fossil fuels.
3. Volcanic emissions, including silicate microparticles and acid gases, blasted into into the stratosphere by plinean volcanic eruptions. The year 1816 was known as the year without summer because so much sulphur dioxide (which turned into small sulphuric acid aerosols) was thrown into the stratosphere by the eruption of Tambora in 1815 that the aerosol layer cooled the earth's surface by several degrees. NASA has a short movie showing what happens.
4. Dust from dust storms on land.

15.5 What is the Evidence for Climate Change?

Table 15.22:

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

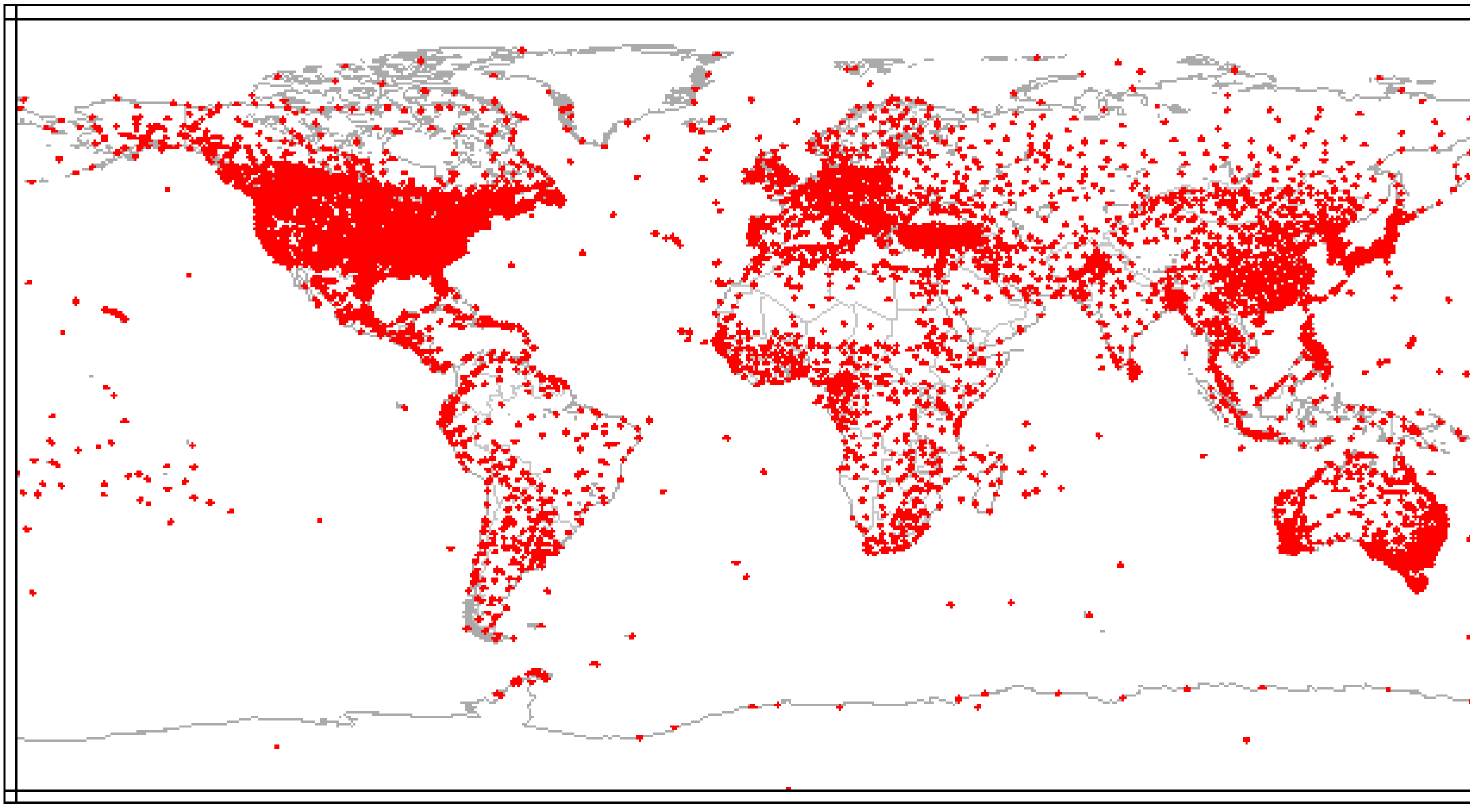
The plot above shows that earth surface is warming. Now let's look at the evidence used to make the plot.

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.

Table 15.23:



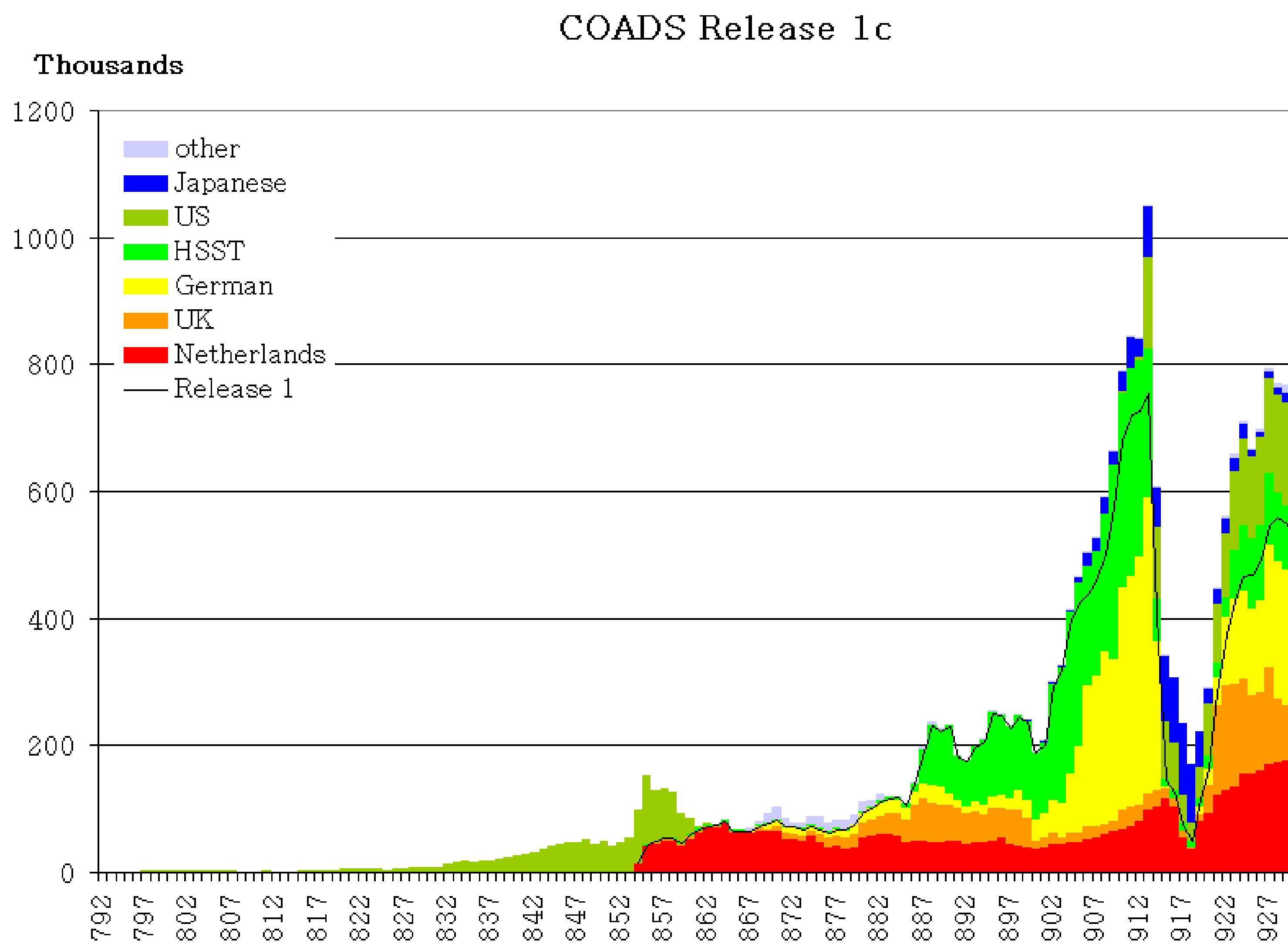
Map of land stations in the Global Historical Climatology Network where air temperature was measured on land and islands. From: NOAA National Climate Data Center.

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 theAdvanced 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.

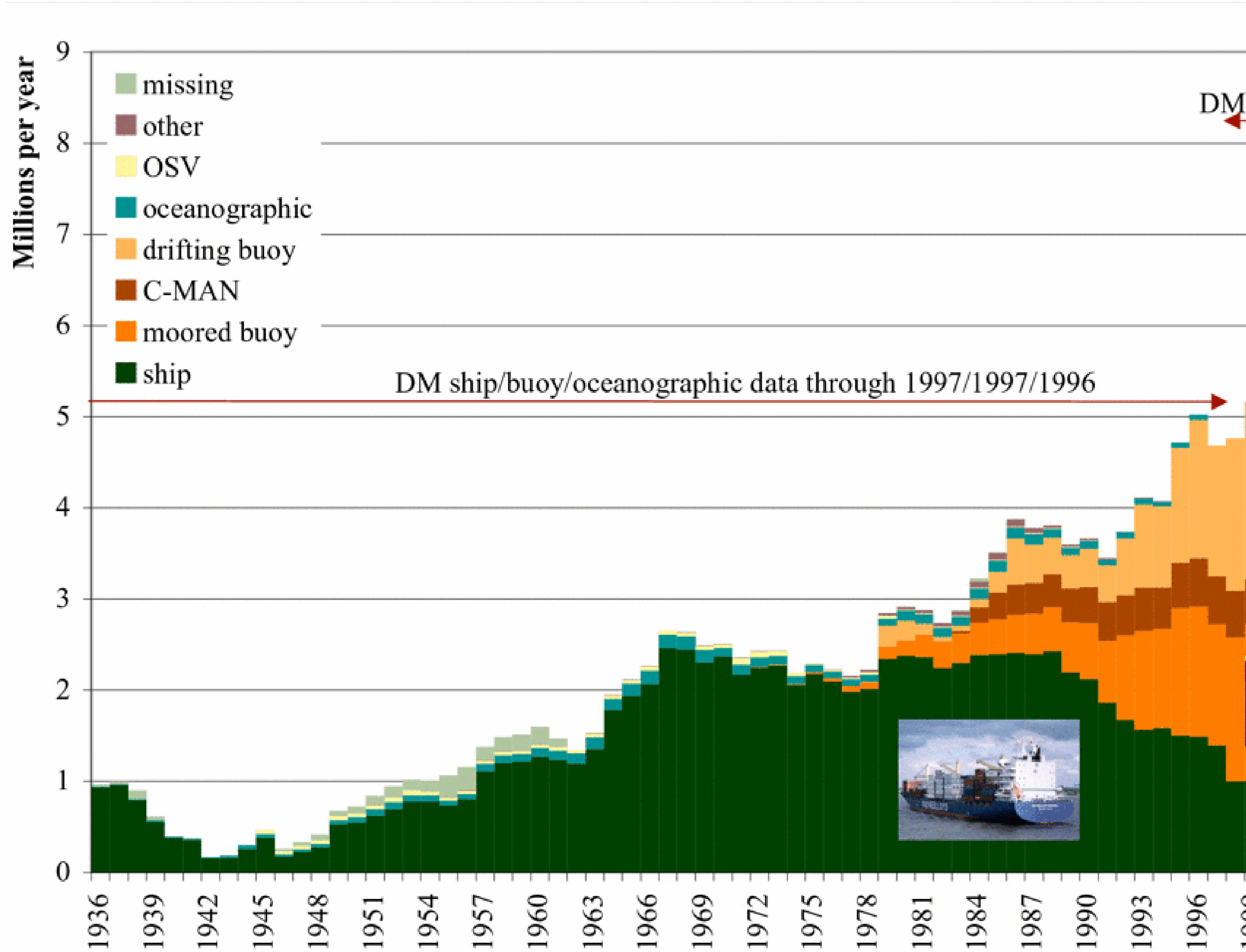
4. Before 1978, all observations at sea were made from ships using thermometers to measure water samples collected in buckets (bucket temperature) or to measure water drawn into the ship to cool the engines (injection temperature). Approximately 185,000,000 observations have been collected, evaluated, and tabulated through theInternational 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.

Table 15.24:



Number of reports of marine weather reports each year included in the International Comprehensive Ocean-Atmosphere Data Set (From NOAA Climate Diagnostics Center).

Table 15.25:



Number of reports of marine weather reports each year included in the International Comprehensive Ocean-Atmosphere Data Set in the period 1936 to 2005 in release 2.3 of the data set. Click on the image for a zoom. From International ICOADS.

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

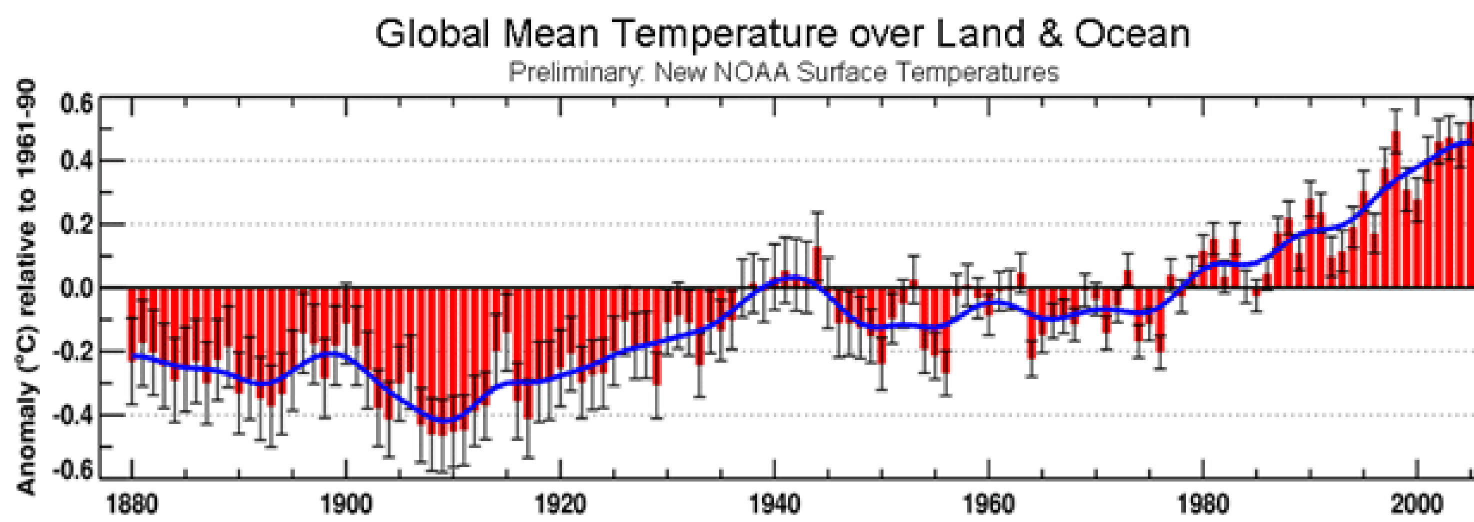
For more information on measurements of water and air temperature at sea read the page on measurements of sea surface temperature in Climate Change 2001: The Scientific Basis by the Intergovernmental Panel on Climate Change.

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.

Table 15.26:



Global average of sea-surface temperature calculated usingSmith and Reynolds techniques, with edtimates of errors in the 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 theIntegrated 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 Expedition 303, red circles = primary sites planned for Expedition 306, and open circles = alternate sites. From Expeditions 303 and 306 Scientific Prospectus, Introduction.

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.
8. Finally, look at the graph of climate change over the past 400,000 years from the Vostock Ice Core from Introduction to Climate Change to see how data from one ice core was used to reconstruct the climate in Antarctica..

Left: Location of Greenland ice cores.Right From North Greenland Ice Core Project. Photo of an ice core. From Kennedy (2006).

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.

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.

Look at the data and how data are collected at NOAA's Paleoclimate web site, beginning with the Instrumental Record for the past 100 Years.

Then read the Paleoclimate Data for the Last 1000 Years.

Then read about Paleoclimate Data for Before 1000 Years Ago.

Here are a few more plots: Global-average Surface Temperature, Average US Temperature, Many Maps of Temperature Trends. See also Temperature Trends at Selected Stations.

15.6 Modeling the Climate System

This Much We Know

1. Greenhouse gases keep earth warm.
2. Greenhouse gas concentration is increasing, mostly a as a result of human activity, including deforestation and burning of fossil fuel.
3. Earth's climate is warming due to increasing greenhouse gas concentrations in the atmosphere.
4. Earth's climate is the result of many interacting systems.

But, What About The Next 100 Years?

> Ii's tough to make predictions, especially about the future. Yogi Berra

Forecasts of climate change are mostly based on models of the physical climate system assuming that the present rate of increase will continue and that carbon dioxide concentrations in the atmosphere will increase to about 700 parts per million by 2100. The Intergovernmental Panel on Climate Change predicts:

1. Average surface temperature of earth will warm by 2°– 6°C.
2. Sea levels will rise by about 0.5 m.

Accuracy of Forecasts For The Next Century

Are these forecasts accurate? The answer depends on many factors.

Carbon Dioxide Concentrations Will carbon dioxide concentrations in the atmosphere continue at the present rate? The best answer is: We don't know.

1. The answer depends on economic, political, and geological factors.
2. How fast will countries develop? This depends on economic activity in all countries, but economic forecasts are not possible, even one year into the future.
   (a) The Intergovernmental Panel on Climate Change has proposed several possible scenarios. The most widely used is called Business as Usual.
   (b) The Business as Usual scenario assumes developing countries will have constant, high levels of economic growth and developed countries will have constant, low levels of growth. This will result in African countries having higher gross domestic products than the united States in one hundred years. Is this realistic? "The dimensions of the problem can be illustrated by the case of South Africa. In 2000, this country's GDP per head, converted from nominal values using exchange rates, was only 12% of the US level. By 2050, the A1 marker scenario projects that the per capita income of South Africans on this basis will have reached more than four times the US level in 2000, and about twice the level that the US will have reached in 2050. And by 2100, this scenario projects that the per capita income of South Africans will be approaching twenty times the US level in 2000, and more than four times the US level at the end of the 21st century. "In the case of the B1 marker scenario (and other scenarios in the B1 family, one of which yields the lowest levels of emissions in the course of the century), the projected levels of average income in both countries in 2100 are somewhat lower than in the A1 marker scenario, but the level of affluence of South Africans exceeds that of Americans by an even wider margin than in the A1 projections. The total output of goods and services in South Africa in 2100, according to these downscaled A1 scenario projections, will be comparable to that of the entire world in 1990." From Ian Castles inIPCC Emissions Scenarios: The Case for a Review.

(c) The forecasts also assume no global disasters such as a world war or a global pandemic killing many people.

3. How will political decisions influence the use of fossil fuels? Will governments provide incentives for use of alternate energy sources such as nuclear power plants, solar energy farms, or wind power?
4. Are there enough reserves of low-cost, easily used fossil fuels to continue the increase? How much oil, gas, and coal remain to be found?
   (a) Will oil become too expensive to use in cars or power plants?
   (b) Will we substitute coal or natural gas for oil?
   (c) Will we begin to use methane hydrates?
5. Because of this uncertainty, projected concentrations in the year 2100 range from 400 to 1200 ppm (parts per million).

Climate Models Are climate models sufficiently complex? The best answer is: We don't know.

1. Thus they must include atmospheric, land, and ocean components.
2. They should resolve the important variability in time and space.
3. And, they must run for hundreds of years.
4. But detailed, complex models cannot run for long times. They cannot include all important processes. Compromises are needed.
5. Many important climate processes are not well known.
   (a) We don't know enough about how clouds will influence reflected solar radiation (sunlight).
   (b) We know little about aerosols (microscopic particles in the air).
      i. How do they influence absorption and reflection of sunlight?
      ii. How many, and what type will be emitted by human activity
   (c) We don't know if solar activity will change, and how the change will influence climate.
   (d) We don't yet know or understand all the important feedbacks in the climate system. Here are just a few oceanic examples.
      i. If ocean surface waters warm, will primary productivity by phytoplankton change?
      ii. Will winds change? If they do, will they transport more or less iron to the ocean as dust particles?
      iii. If iron transport changes, will primary productivity change?
      iv. If ocean surface water warms, the stability of the ocean changes. How will this influence ocean currents and the upwelling of nutrients? Will El Niño change?
      v. We don't know if the tropical Pacific will become cooler (more like La Niño conditions) or warmer (more like El Niño), yet the tropical Pacific strongly influences global weather patterns (Vecchi et al 2008).
      vi. Will the change in stability influence the deep circulation?
      vii. Will changes in the deep circulation lead to abrupt climate change?
      viii. Will warmer water lead to the release of methane from methane hydrates? Methane is a potent greenhouse gas.

Past Performance

We can gain some insight into the possible accuracy of climate models by observing how well they predict past change.

1. Present models cannot determine how the tropical Pacific will respond to global warming.
2. Most coupled ocean-atmosphere-land models cannot reproduce the present climate. They must be adjusted to get the correct climate. The adjustments are called flux adjustments because the flux of heat and water between the ocean and the atmosphere is not known well so it must be adjusted.
3. Climate models cannot predict changes in past climate of earth. For example, they cannot predict abrupt climate change that occurred many times in the past.
4. Climate models have predicted the observed warming over the past 15 years.

Overall It is perhaps fair to say that future predictions are difficult to make.

1. Some future processes cannot be modeled. We cannot predict:
   (a) Epidemics, war, and political actions, and economic activity, all of which influence emissions of greenhouse gases. IPCC reports just assume various possible ranges of future emissions, with emphasis on "business as usual."
   (b) Volcanic activity.
   (c) Future changes in solar activity.
2. Most or all models used in geoscience have been wrong. Earth systems are more complex than we know or can model. See Useless Arithmetic: Why Environmental Scientists Can't Predict the Future by Orrin H. Pilkey, Linda Pilkey-jarvis (2007), Columbia University Press. But I have studied the climate models and I know what they can do. The models solve the equations of fluid dynamics, and they do a very good job of describing the fluid motions of the atmosphere and the oceans. They do a very poor job of describing the clouds, the dust, the chemistry and the biology of fields and farms and forests. They do not begin to describe the real world that we live in. The real world is muddy and messy and full of things that we do not yet understand. It is much easier for a scientist to sit in an air-conditioned building and run computer models, than to put on winter clothes and measure what is really happening outside in the swamps and the clouds. That is why the climate model experts end up believing their own models. Freeman Dyson Heretical Thoughts About Science and Society, 8 August 2007.
3. We will never be able to test the predictions.
   (a) We have only one earth and one future.
   (b) The future is not the same as the past. The ability to predict changes that occurred in the past does not mean that we will be able to predict future changes even if we can ignore political, economic, solar, and volcanic activity.

Consequences of Global Warming Are Uncertain

1. Some areas, mostly polar regions will be much warmer. This is already happening.
2. We do not know how much temperature will rise in smaller areas and in populated areas.
3. We do not yet know how climate change will influence the distribution of rainfall, tropical storms, and droughts.
4. We have only imperfect understanding of how warming will change ecosystems.
5. The consequences are not all bad. Overall, economists estimate the benefits will be about the same as the costs. For example:
   (a) Canada, New England, and Russia benefit from warmer winters and a longer growing season.
   (b) But, in other areas the use of air conditioning in summer will rise.

Decadal Predictions Are Probably Useful

If forecasts for the next century are very uncertain, perhaps we can produce better forecasts for shorter times. Looking carefully at the assumptions used for climate forecasts, and at the complexity of the forecast models, we may conclude that the forecasts for the next few decades may have useful accuracy.

1. Is a third world war likely? Not really.
2. Will there be a global pandemic that greatly slows global carbon emissions? Possibly, but not likely.
3. Will economies continue to grow at the present rate? Maybe, but not in the next few years.
4. Will fossil fuels become so expensive that they will be replaced by alternate energy sources? Possibly, it is already happening. But, fossil fuels will be the main source of power for the next few decades.
5. Do we understand all feedback mechanisms in the earth system? No, but we probably understand the most important feedbacks.
6. Are the models sufficiently complex? Probably. Advances have been made in the simulation of past climate variations. Independently of any attribution of those changes, the ability of climate models to provide a physically self-consistent explanation of observed climate variations on various time scales builds confidence that the models are capturing many key processes for the evolution of 21st-century climate. Recent advances include success in modelling observed changes in a wider range of climate variables over the 20th century (e.g., continental-scale surface temperatures and extremes, sea ice extent, ocean heat content trends and land precipitation). From IPCC (2008).
7. Will earth climate continue to warm. Probably, because the excess carbon dioxide in the atmosphere will continue to cause warming for decades even if no more is put into the atmosphere by human activity. The climate system has inertia.
   (a) Warmer and fewer cold days and nights over most land areas are virtually certain (IPCC, 2007).
   (b) Warmer and more frequent hot days and nights over land are virtually certain (IPCC, 2007). Knowledge of the climate system together with model simulations confirm that past changes in greenhouse gas concentrations will lead to a committed(continuing) warming and future climate change... Committed climate change due to atmospheric composition in the year 2000 corresponds to a warming trend of about 0.1°C per decade over the next two decades, in the absence of large changes in volcanic or solar forcing. From IPCC (2007).

Thus, overall, climate forecasts for the next few decades may be accurate enough that they should be taken seriously. The Precautionary Principle should guide our actions (see below).

15.7 Climate Change Outcomes and Policy Issues

> EVERYTHING IS CONNECTED. EVERYTHING IS UNCERTAIN. ANYTHING MIGHT CAUSE ANYTHING. DON'T DO ANYTHING ... SOMETHING HAS TO BE DONE! - *Michael Markels (Cited in Wired Magazine, 8 (11), November 2000)*
>
> Maintaining the Earth's climate within habitable boundaries is probably the greatest "public goods game" played by humans. However, with >6 billion "players" taking part, the game seems to rule out individual altruistic behavior. Thus, climate protection is a problem of sustaining a public resource that everybody is free to overuse, a "tragedy of the commons" problem that emerges in many social dilemmas. - Milinski et al (2006)

Many people, most governments, and large industries have concluded that climate change is happening. The important questions now are:

1. How serious is the threat of warming?
2. If it is serious, how best to respond to the threat?
3. Is it better to wait until the threat becomes clearer?
4. Or should we act now, without clear knowledge of what will happen?

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.

For a contrarian view on global warming, read HERETICAL THOUGHTS ABOUT SCIENCE AND SOCIETY by Freeman Dyson.

Direct Physical Effects

- Melting of glaciers and a consequent rise in sea level, already documented (**Figure** 15.1)
- Sea level rise of 18-59 cm predicted by 2100
- River flooding followed by drought
- Coastal flooding and shoreline erosion

- Melting permafrost, leading to release of bog methane (CH_4) increasing warming via positive feedback*

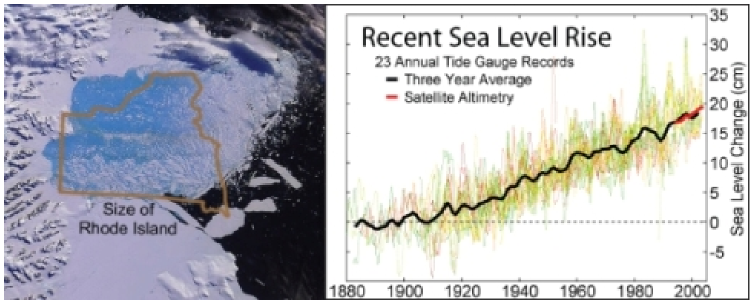


Figure 15.1: Glacial melting (left) and a rise in sea level (right) are two consequences of global warming. The left image shows the Larsen Ice Shelf B, which broke up during February of 2002 after bordering Antarctica for as long as 12,000 years. Excluding polar ice caps, 50% of glacial areas have disappeared 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.

- 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 (**Figure** 15.2)
- Further reductions in the Ozone Layer (due to cooling of the stratosphere)

Figure 15.2: 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 onPresent 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** 15.3)

- 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

Figure 15.3: 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.

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** 15.4 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.

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.

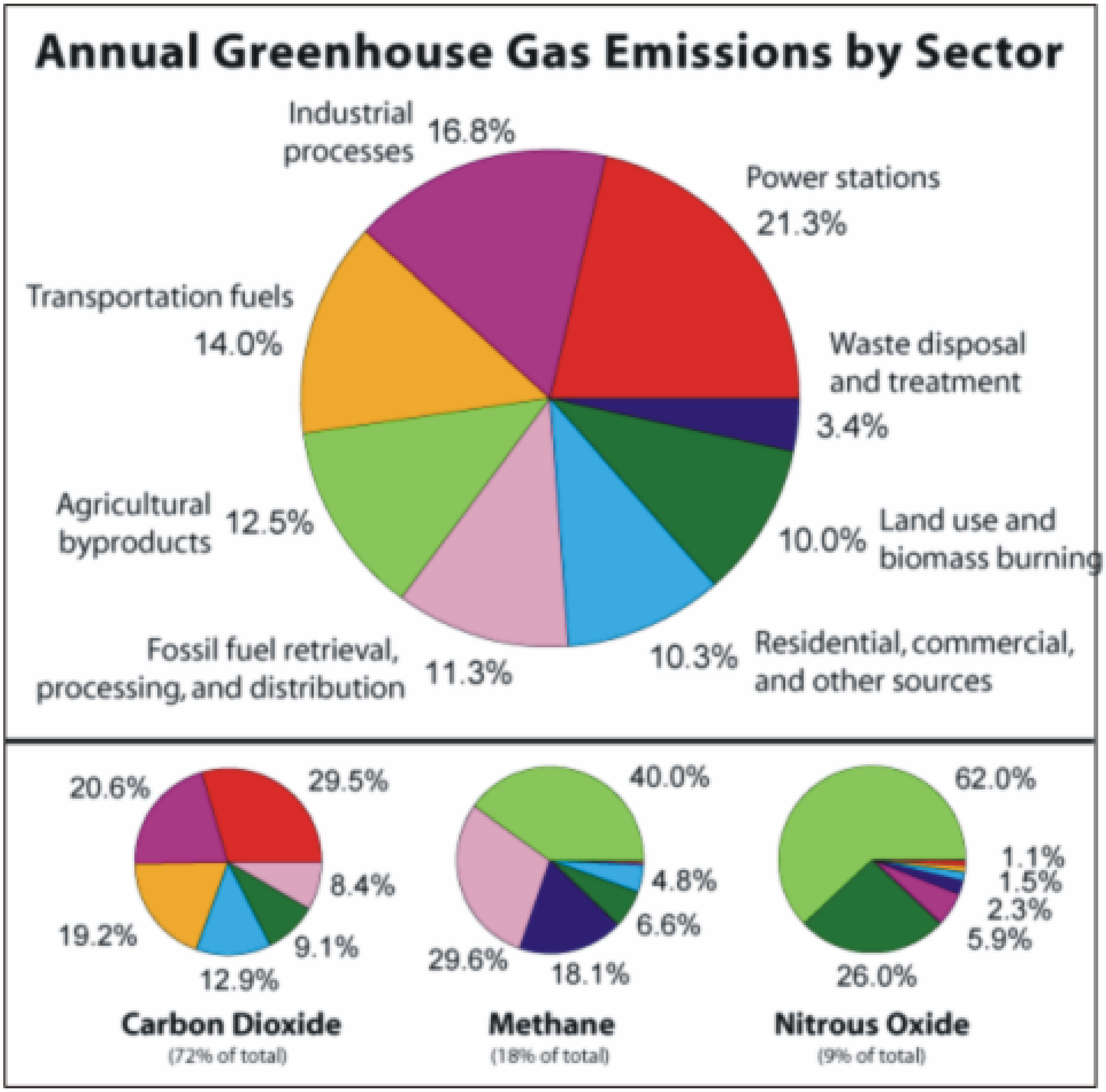


Figure 15.4: Global greenhouse emissions during 2002 show sources for each of the three major greenhouse gases. Knowing the causes makes finding solutions clear, but not necessarily easy!

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.

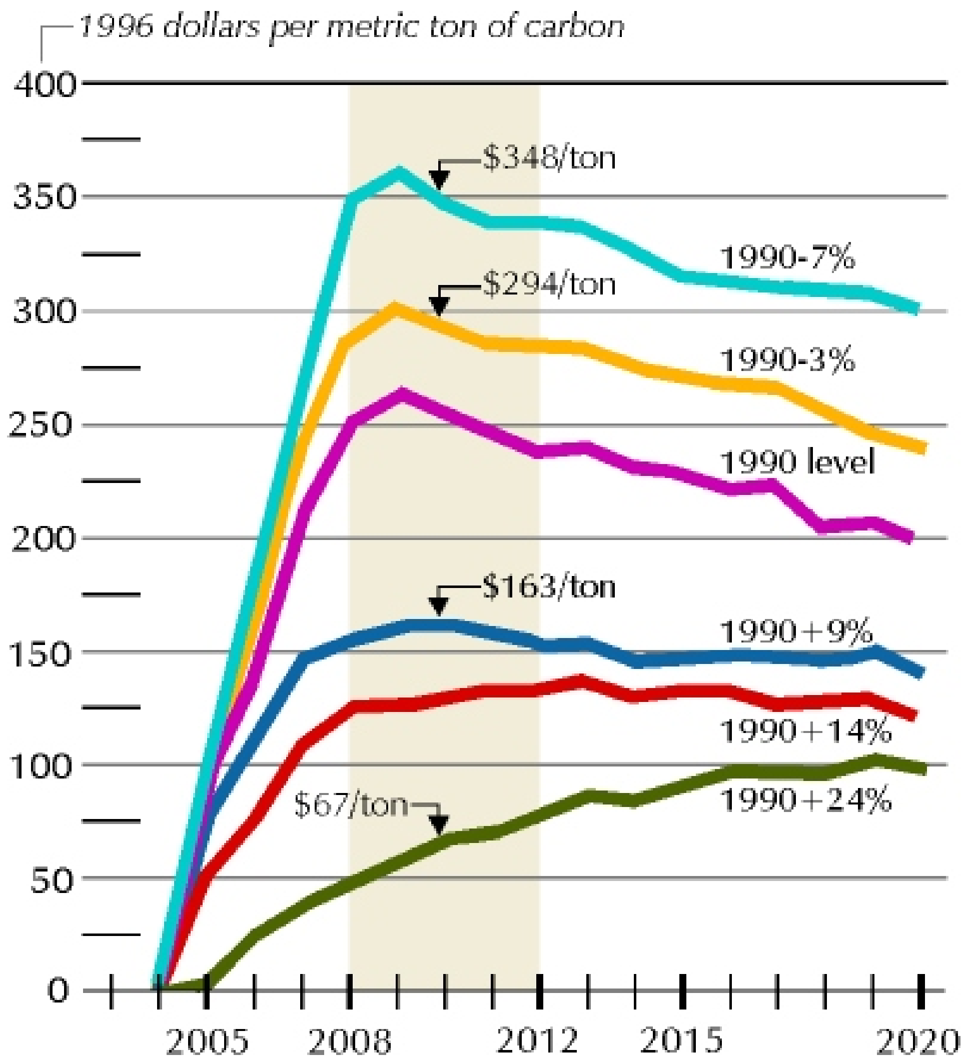
1. What is being proposed? The primary document is the Kyoto Protocol to the United Nations Framework Convention on Climate Change. According to the protocol "The Parties included in Annex I [the developed countries of the world] shall, individually or jointly, ensure that their aggregate anthropogenic 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?
   (a) Read the US Congressional Research Service (CRS) abstract of their report on Global Climate Change: Major Scientific and Policy and thereport (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.
   (b) Then go the the Energy Information Administration's Analysis and Report and read about the implications for the US economy.
   (c) 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:
      i. It excludes the world's most populous countries, China and India, because they are developing countries. The US wanted meaningful participation by all countries.
      ii. There is no clear statement of penalties for failure to implement the protocol.
      iii. 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?
      iv. 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.
      v. 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.
      vi. It penalizes the US more than other countries because our economy has been growing strongly compared with other countries that have ratified the protocol.
   (d) Although some of these problems were mitigated through later meetings of the Conference of the Parties (COP), the problems are still not completely solved.
   (e) 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.
   (f) 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?

Table 15.31:

	Carbon price needed to meet Kyoto goals in the US. Price increases encourage a reduction in the use of energy services (heating, lighting, and travel, for example), the adoption of more energy-efficient equipment, and a shift to less carbon-intensive fuels. The carbon price reflects the amount fossil fuel prices in the US, adjusted for the carbon content of the fuel, must rise to achieve the removal of the last ton of carbon emissions that meets the carbon reduction target in each case. From; Energy Information Agency. Note: 10 barrels of oil contain about 1 metric ton of carbon. US EPA Green Power Equivalency 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.

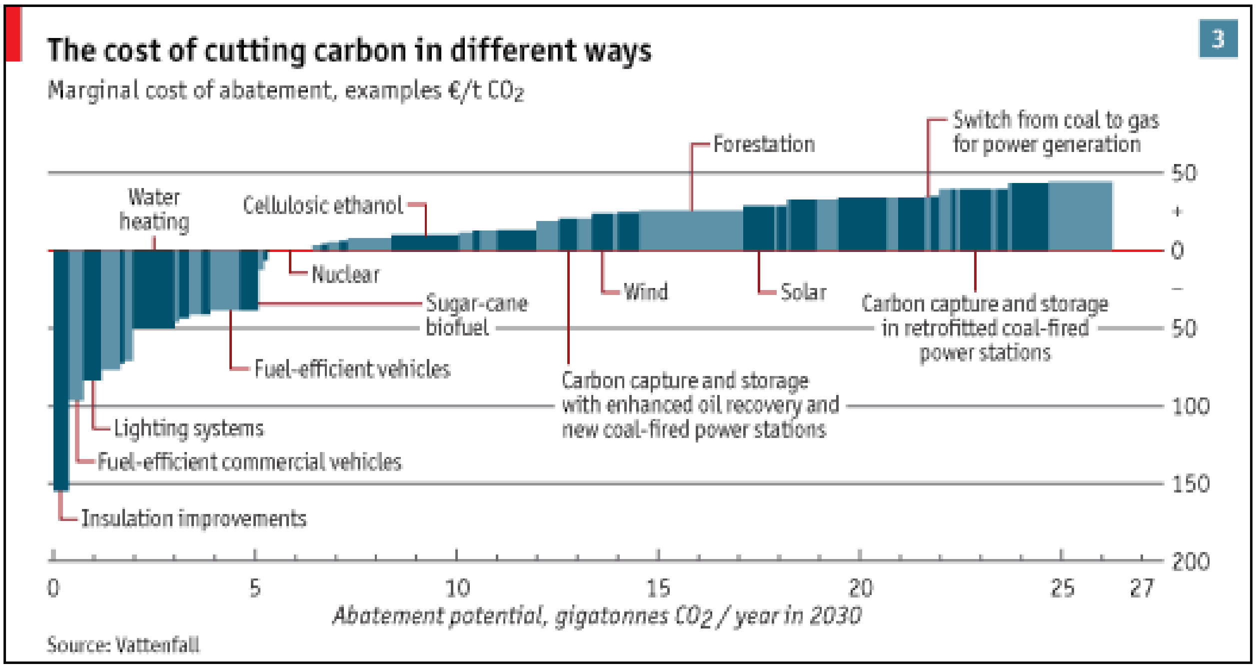
1. Command and control. The government decides what must be done. For example, the US Congress is proposing to set limits on gasoline mileage for cars. This approach is rarely effective. Drivers in the US switched from small cars to large, less-fuel efficient cars, despite government regulations on fuel 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.

Table 15.32:



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

An Overlooked Argument

We know that climate changes, and the changes influence society. As greenhouse gas concentrations increase, the probability of climate change increases. Climate change is inevitable. We know furthermore that many societies are especially vulnerable to climate change. Coastal communities in Florida are vulnerable to increased hurricane frequency and intensity. The Maldives are vulnerable to rising sea level.

If climate will change, we need to reduce society's vulnerability to change. This aspect of the problem has been largely ignored.

Other Sources (if you like to read a lot):

1. Resources for the Future has a good Guide to Climate Policy.
2. The Sierra Club has an Overview of Global Warming and Energy.
3. The New Scientist provides a European Perspective.
4. Greenpeace's Save the Climate Campaign
5. Wall Street Journal Editorial 19 January 2006 page A14: Although many developed countries that have signed the Kyoto Protocol have criticized the USA for not signing the Kyoto Protocol, they have failed to reduce their own emissions. Denmark has increased emissions 6.3% since 1990 although they committed to reducing emissions by 21%. USA emissions are up 15.8% since 1990, Greece's emissions are up 23%, Canada's are up 24%.

15.8 End of Chapter Review & Resources

Chapter Summary

The awarding of the 2007 Nobel Peace Prize to the Intergovernmental Panel on Climate Change (IPCC) and former US Vice President Al Gore recognizes the potential impact of global warming on the economic, social, and political welfare of the world. The greenhouse effect is an ecosystem service which warms the Earth to temperatures which support life. The greenhouse effect involves water, carbon dioxide, methane, and ozone, which absorb heat that would otherwise be radiated out into space. Earth's atmosphere maintains an equilibrium between heat added by sunlight and heat lost by radiation. The atmosphere of Mars is too thin to hold heat, and that of Venus is so thick that temperatures reach 500°C. In 2000, the major greenhouse gases were CO_2, CH_4, and NO; CFCs and H_2O contribute, as well. Global warming refers to an increase in the Earth's temperature of 0.74°C (1.33°F) within the past 100 years. Paleoclimatologists document changes in the Earth's temperature over millions of years which cycle between tropical and ice age extremes – a variation of 10°C. Greenhouse gases, especially CO_2 levels, often correlate with temperature changes. Deforestation and agriculture – by reducing levels of CO_2 uptake – may have initiated warming 8,000 years ago. Most scientists today agree that fossil fuel combustion, deforestation, and agriculture contribute to greenhouse gases and the greenhouse effect. Global warming can cause physical changes for the Earth: melting of glaciers and permafrost, changes in precipitation patterns, temperature extremes, warming and acidification of the oceans, and ozone depletion. Melting of oceans and permafrost can release methane, resulting in a "runaway greenhouse effect." Ecological effects may include loss of biodiversity and addition of still more CO_2 to the atmosphere. Socioeconomic threats include crop losses, increased disease, water scarcity, and coastal flooding. Population growth and socioeconomic factors (especially interference with third world development) can combine to produce political instability and conflict. Most greenhouse gases are products of fossil fuel combustion, so reduced use, increased efficiency, and alternative fuel development are primary means of prevention of climate change. CO_2 uptake can be increased by eliminating deforestation, reforestation, and green roofs technology. Legislation from local to international levels can cap emissions and develop carbon offset trading. Careful urban planning can increase the efficiency of transportation and energy use. Planetary engineering could enact radical changes in technology, culture, or the biosphere. Support of third world efforts to develop without adding greenhouse gases could improve global stability. Every potential solution has costs and benefits which must be carefully considered; tradeoffs are necessary.

Review Questions

1. Explain the mechanism of the greenhouse effect.
2. Compare the effects of the greenhouse effect on Mars and Venus to that on Earth.
3. Define and quantify global warming.
4. Describe paleoclimatic changes over the course of Earth's history. How are these data collected, when no one was around to measure temperatures?
5. Summarize the evidence for greenhouse gases as the cause of recent global warming.
6. Discuss the significance of global warming for Earth's ecosystems.
7. Relate global warming to current global stability.
8. Connect the atmospheric gases that absorb the Earth's thermal radiation to their sources.
9. Combustion of fossil fuels is a common denominator for many problems related to Atmospheric and Water Resources. Clarify the connections for as many problems as you are able.
10. Distinguish between and describe the importance to global warming prevention of carbon sequestration, carbon sinks, carbon offsets, emission caps, emissions trading, and carbon neutrality.
11. How is the Greenhouse Effect both positive and negative?

12. How might we do a better job of building the costs of global warming into the economics of fossil fuel use, deforestation, agriculture, and cattle production?

Further Reading / Supplemental Links

- NASA: Evidence for Climate Change: http://climate.nasa.gov/evidence/
- For more information on greenhouse gases, see the expert's page on greenhouse gases written by the Atmospheric Radiation Measurement (ARM) Program of the U.S. Department of Energy (DOE).
- For more information on climate change, read the US Global Change Research Information Office's pages on global warming.
- Read the section on Climate at the Environmental Protection Agency's Climate Change Web Site.
- The University Center for Atmospheric Research has a simple tutorial on The Greenhouse Effect.
- United Nations Environmental Program's UNEP Global Resources Information Database (GRID) office in Arendal Norway has written useful web pages on Planets and Atmospheres, the Greenhouse Effect, and Radiative Forcing, in the Vital Climate Graphics web page. They explain the important ideas.
- For more information on the importance of CO_2 and aerosols in the atmosphere, read the Executive Summaries for
  - Chapter 4 Atmospheric Chemistry and Greenhouse Gases
  - Chapter 5 Aerosols, their Direct and Indirect Effects

- Intergovernmental Panel on Climate Change IPCC Third Report on Climate Change 2001: The Scientific Basis.
- Stokstad gives a good overview of the ways to reconstruct paleoclimate.

- Robert Lee Hotz, *Huge Dust Plume from China Cause Changes in Climate. Wall Street Journal Online*, 20 July, 2007;
- http://online.wsj.com/public/article/SB118470650996069354-buQPf_FL_nKirvopk___GzCmNOq8_-20070818.html?mod=tff_main_tff_top.
- NASA, *The Greenhouse Effect. NASA Facts Online*, NASA Goddard Space Flight Center, NF-182 June 1993;
- http://www.panda.org/about_wwf/what_we_do/climate_change/index.cfm
- EPA on Climate Change: http://www.epa.gov/climatechange/index.html

Vocabulary to Know

- **anthropogenic sources** - Sources of pollution related to human activities.
- **carbon (CO_2) sink** - A reservoir which increases absorption of CO_2 – e.g. a forest plantation.
- **carbon offsetting** - Mitigating or reducing greenhouse gas emissions, often as a trade-off from one location to another.
- **carbon sequestration** - Process which removes CO_2 from the atmosphere.
- **carbon-neutral** - Describes an individual, activity, industry, or a political unit which balances CO_2 release with activities which sequester carbon.
- **emissions cap** - Upper limit on CO_2 (or other pollutant) release; may be tradable or sellable.
- **emissions trading** - Reducing greenhouse emissions by purchasing or exchanging means of reducing CO_2 in exchange for rights to release CO_2 .
- **global warming** - The recent increase in the Earth's average near-surface and ocean temperatures.
- **greenhouse effect** - The trapping by the atmosphere of heat energy radiated from the Earth's surface.

- **greenhouse gas** - Atmospheric substance which transmits solar radiation but absorbs infrared radiation: CO_2, CH_4 and NO, for example.
- **planetary engineering** - Radical, often global changes in technology, culture, or the biosphere management.
- **runaway greenhouse effect** - A positive feedback loop in which increasing temperature triggers the release of more greenhouse gases, which further increase temperature, which releases more gases.

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The biogeochemical cycles of H, C, N, O and S are coupled via biologically catalysed electron transfer (redox) reactions. The metabolic processes responsible for maintaining these cycles evolved over the first ca 2.3 Ga of Earth's history in prokaryotes and, through a sequence of events, led to the production of oxygen via the photobiologically catalysed oxidation of water. However, geochemical evidence suggests that there was a delay of several hundred million years before oxygen accumulated in Earth's atmosphere related to changes in the burial efficiency of organic matter and fundamental alterations in the nitrogen cycle. In the latter case, the presence of free molecular oxygen allowed ammonium to be oxidized to nitrate and subsequently denitrified. The interaction between the oxygen and nitrogen cycles in particular led to a negative feedback, in which increased production of oxygen led to decreased fixed inorganic nitrogen in the oceans. This feedback, which is supported by isotopic analyses of fixed nitrogen in sedimentary rocks from the Late Archaean, continues to the present. However, once sufficient oxygen accumulated in Earth's atmosphere to allow nitrification to out-compete denitrification, a new stable electron 'market' emerged in which oxygenic photosynthesis and aerobic respiration ultimately spread via endosymbiotic events and massive lateral gene transfer to eukaryotic host cells, allowing the evolution of complex (i.e. animal) life forms. The resulting network of electron transfers led a gas composition of Earth's atmosphere that is far from thermodynamic equilibrium (i.e. it is an emergent property), yet is relatively stable on geological time scales. The early coevolution of the C, N and O cycles, and the resulting non-equilibrium gaseous by-products can be used as a guide to search for the presence of life on terrestrial planets outside of our Solar System.

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Chapter 16

Water: Use, Pollution & Remediation

16.1 Introduction

Water is essential for all life on Earth and is an important regulator of climate. While water covers as much as 71% of the Earth's surface, only about 1% is available for human use while the rest is taken up by glaciers and ice, which is mostly available in ground water. Both water quantity and quality are concerns in the new millenium. In many parts of the world access to clean drinking water is not available, and in many developed nations over use of water is a serious concern. Pollution and water mining (over use of ground water) are leading to water shortages, which lead to social instability and economic issues.

Chapter Objectives

- Developing countries may be able to afford water treatment systems, but people still need incentives to use conservation steps.
- Describe the physical characteristics of water that make it a valuable resource for agricultural, industrial, and domestic uses.
- Discuss the risks that water pollution poses to human and environmental health.
- Explain why water shortages are increasingly frequent throughout the world.
- Discuss why 1.1 billion people (one fifth of the people on Earth) do not have access to safe drinking water.
- Explain where fresh and saltwater pollution come from.
- Discuss how pathogen born diseases are caused by water pollution.
- Describe why conserving water and protecting water quality is important to human health and the environment.
- Describe how water pollution reduces the amount of safe drinking water available.
- Discuss who is responsible for preventing and cleaning up water pollution.
- Discuss the benefits and costs of different methods of irrigation, both to the farmer and to the watershed.
- Analyze the need for laws to control water resources, and compare water rights doctrine in the eastern U.S. to that of the western states.
- Understand the different kinds of water pollution issues.
- Understand water mining and over use issues.

- Understand the difference between water quality and water quantity.
- Understand the different methods used for water remediation.
- Discuss how water is treated to eliminate harmful particles.
- State what governments and international organizations can do to reduce water pollution.
- Describe several ways water can be conserved

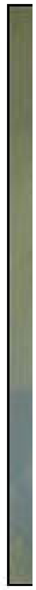
16.2 Water for Life

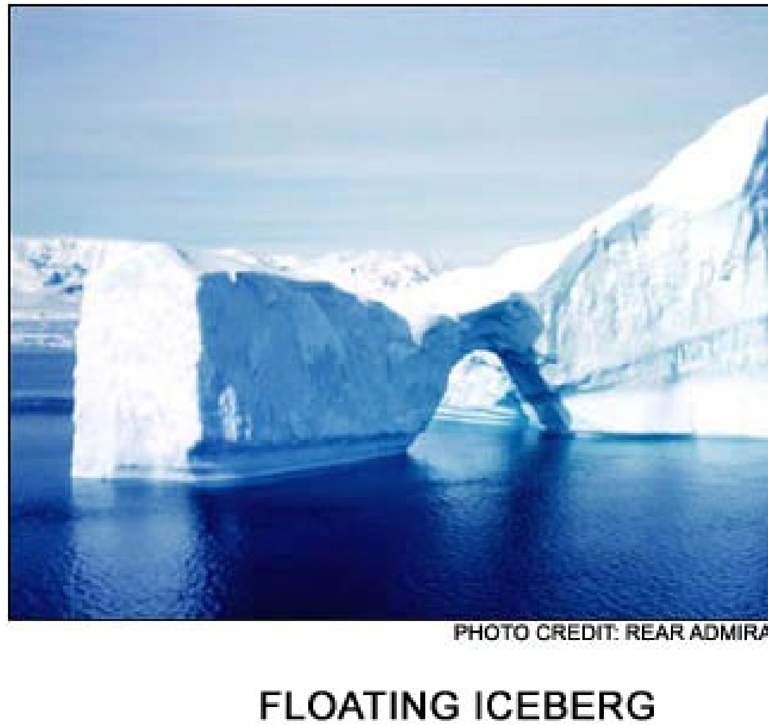
Water is an abundant substance on earth and covers 71 percent of the earth's surface. Earth's water consists of three percent freshwater and 97 percent saltwater. All living organisms require water in order to live. In fact, they are mostly comprised of water. Water is also important for other reasons: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

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

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

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





AV

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

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

16.3 World Water Supply and Distribution

Water is everywhere. More than 70% of the Earth's surface is covered by water. The Earth has a limited supply of water that we can use. There are supplies of freshwater in lakes, rivers, streams, swamps, reservoirs, and even underground water rich regions of soil and rock, called **aquifers**. Almost anywhere you stand, there is water somewhere beneath you. Sometimes that water is just several meters below you, sometimes it is deeper within the Earth.

Still, this supply of freshwater is less than 1% of all of the water on Earth. Why is so little water available for human use? Two reasons:

- For most of our needs, humans cannot use saltwater, which makes up 97-98% of all water on Earth.
- Humans cannot use most of the freshwater on Earth, because is frozen in glaciers and icebergs, mainly in Greenland and Antarctica (Figure 21.10).

A common misconception is that water shortages can be solved by desalination, removing salt from seawater. This is because the desalination process requires so much energy and is so costly, that it is not an economical way to increase freshwater resources.

Water Distribution & Supply

Look closely at the climates of different regions around the Earth. Some places have water rich climates, while many others do not. Roughly 40% of the land on Earth is arid or semiarid, which means it receives little or almost no rainfall.

Global warming affects patterns of rainfall and water distribution. As the Earth warms, regions that currently receive an adequate supply of rain may shift. Regions of Earth that normally are low pressure areas may become areas where high pressure dominates. That would completely change the types of plants and animals that can live successfully in that region.

In 1995, about 40% of the world's population faced water scarcity. Scientists believe that by the year 2025, nearly half of the world's people won't have enough water to meet their daily needs. Nearly one quarter of the people in the world will have less than 500 m^3 of water per person to use in an entire year. A cubic meter of water equals 1,000 liters. That means in certain areas of the world, many people will have less water available in a year than some people in the United States use in one day.

Economic Considerations

A glass of water may be free in a restaurant, but this does not reflect its value as a resource. Water is often regarded as more valuable than gold, because human survival depends on having steady access to it.

Water scarcity can have dire consequences for the people, the economy and the environment. Without adequate water:

- Crops and livestock dwindle and people go hungry.
- Industrial, construction, and economic development is halted.
- The risk of regional conflicts over scarce water resources rises.
- Ultimately some people die from lack of water.

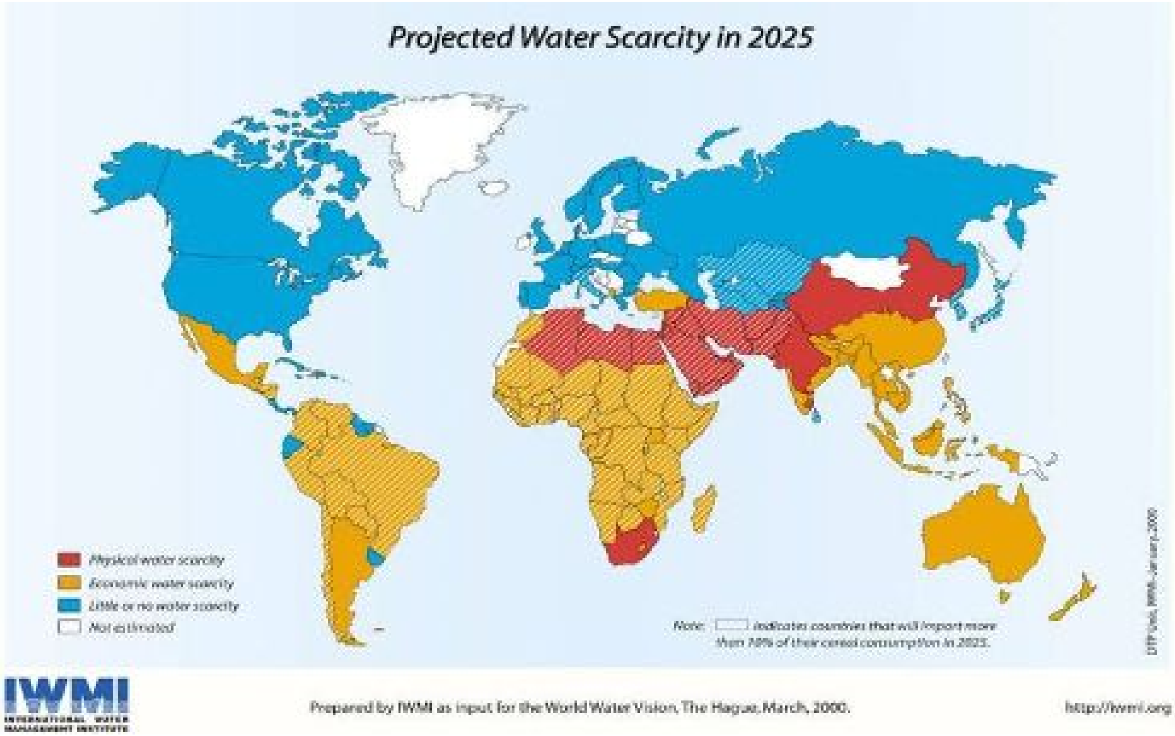


Figure 16.1: http://localhost/International%20Water%20Management%20Institute%20predicts%20expanding%20wat

16.4 Water Use in Different Sectors

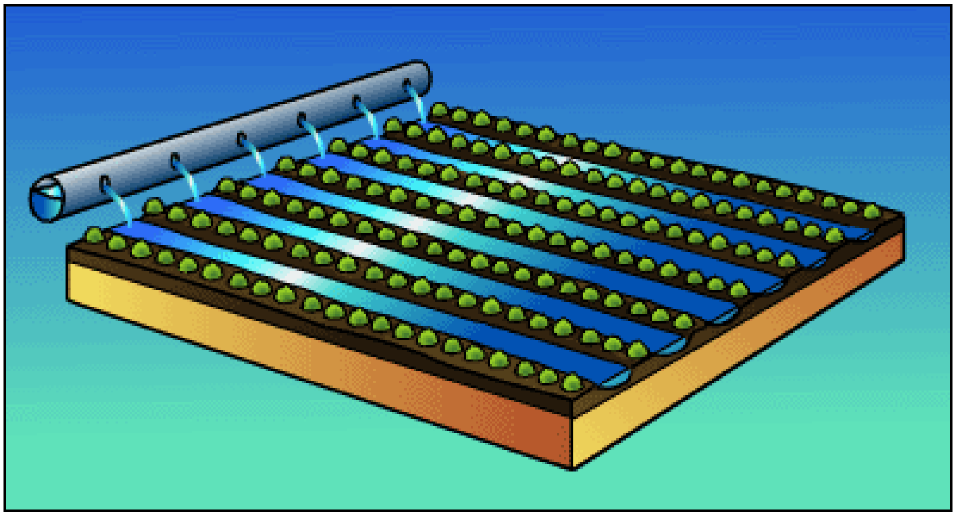
Agricultural Water Use

Agriculture is the single largest user of water in the world. Most of that water is used for irrigating crops. **Irrigation** is the process of transporting water from one area to another for the purpose of growing crops. The water used for irrigation usually comes from rivers or from groundwater pumped from wells. The main reason for irrigating crops is that it increases yields. It also allows the farming of marginal land in arid regions that would normally not support crops. There are several methods of irrigation: flood irrigation, furrow irrigation, drip irrigation and center pivot irrigation.

Flood irrigation involves the flooding of a crop area located on generally flat land. This gravity flow method of water is relatively easy to implement, especially if the natural flooding of river plains is utilized, and therefore is cost-effective. However, much of the water used in flood irrigation is lost, either by evaporation or by percolation into soil adjacent to the intended area of irrigation.

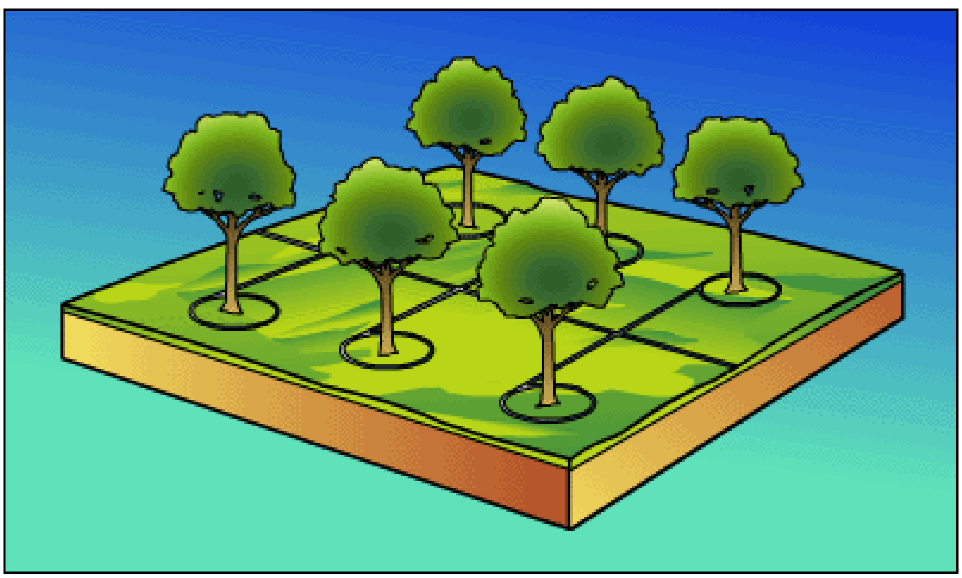
Because farmland must be flat for flood irrigation to be used, flood irrigation is only practical in certain areas (e.g. river flood plains and bottomlands). In addition, because land is completely flooded, salts from the irrigation water can buildup in the soil, eventually rendering it infertile.

Furrow irrigation also involves gravity flow of water on relatively flat land. However, in this form of irrigation, the water flow is confined to furrows or ditches between rows of crops. This allows better control of the water and, therefore, less water is needed and less is wasted. Because water can be delivered to the furrows from pipes, the land does not need to be completely flat. However, furrow irrigation involves higher operating costs than flood irrigation due to the increased labor and equipment required. It, too, involves large evaporative loss.



FURROW IRRIGATION
(EFFICIENCY 60 AND 80 PERCENT WITH SURGE VALVES)

Drip irrigation involves delivering small amounts of water directly to individual plants. Water is released through perforated tubing mounted above or below ground near the roots of individual plants. This method was originally developed in Israel for use in arid regions having limited water available for irrigation. It is highly efficient, with little waste of water. Some disadvantages of drip irrigation are the high costs of installation and maintenance of the system. Therefore, it is only practical for use on high-value cash crops.



DRIP IRRIGATION
(EFFICIENCY 90 to 95 PERCENT)

Center-pivot sprinkler systems deliver water to crops from sprinklers mounted on a long boom, which rotates about a center pivot. Water is pumped to the pivot from a nearby irrigation well. This system has the advantage that it is very mobile and can be moved from one field to another as needed. It can also be used on uneven cropland, as the moving boom can follow the contours of the land. Center-pivot systems are widely used in the western plains and southwest regions of the United States.

PHOTO CREDIT: TIM McCABE, USDA

CENTER PIVOT IRRIGATION

(EFFICIENCY 80 PERCENT WITH LOW PRESSURE SPRINKLER
AND 90 TO 95 PERCENT WITH LEPA SPRINKLER)

With proper management, properly designed systems can be almost as efficient as drip irrigation systems. Center-pivot systems have high initial costs and require a nearby irrigation well capable of providing a sufficiently high flow. Constant irrigation with well water can also lead to salinization of the soil.

Domestic and Industrial Water Use

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

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

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

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

Water Use Control and Policy

Households and industry both depend on reliable supplies of clean water. Therefore, the management and protection of water resources is important. Constructing dams across flowing rivers or streams and impounding the water in reservoirs is a popular way to control water resources. Dams have several advantages: they allow long-term water storage for agricultural, industrial and domestic use; they can provide hydroelectric power production and downstream flood control. However, dams disrupt ecosystems, they often displace human populations and destroy good farmland, and eventually they fill with silt.

Humans often tap into the natural water cycle by collecting water in man-made reservoirs or by digging wells to remove groundwater. Water from those sources is channeled into rivers, man-made canals or pipelines and transported to cities or agricultural lands. Such diversion of water resources can seriously affect the regions from which water is taken.

PHOTO CREDIT: VAHE PEROOMIAN

HOOVER DAM

For example, the Owens Valley region of California became a desert after water projects diverted most of the Sierra Nevada runoff to the Los Angeles metropolitan area. This brings up the question of who owns (or has the rights to) water resources.

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

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

Common law generally gives property owners rights to the groundwater below their land. However, a problem can arise in a situation where several property owners tap into the same groundwater source. The Ogallala Aquifer, which stretches from Wyoming to Texas, is used extensively by farmers for irrigation.

However, this use is leading to groundwater depletion, as the aquifer has a very slow recharge rate. In such cases as this, a general plan of water use is needed to conserve water resources for future use.

16.5 Water Quantity

Groundwater - The Sea Beneath Our Feet

We learned in the chapter on the water cycle that almost all fresh water available for human use is ground water. In this chapter we will learn more about the distribution of groundwater, its chemical properties, and its flow through aquifers.

Groundwater is water that that fills pores in soil and rock. It is formed when precipitation percolates into the ground. If groundwater is available in useful quantities, the layer of groundwater is called an aquifer. Aquifers are the most important water source for irrigation and and domestic use, especially in the western US. Overall, they supply about half the household water used by people in the the United States. Worldwide, groundwater supplies:

1. 50% of all drinking water,
2. 40% of water used by industry,
3. 20% of water used for irrigation. (Fry, 2005).

Major concerns centered on water quantity are:

1. Depletion of aquifers almost everywhere in the world. Water tables are falling almost everywhere.
2. Land subsidence.
3. Contamination of aquifers.

Water Shortages

As we continue to use our precious freshwater supplies, scientists expect that we will encounter several different types of problems. We currently irrigate our crops using supplies of groundwater in aquifers underground. When we have used up these groundwater supplies, we will not be able to grow as many different types of crops or we will have lower yields of the crops we grow. Using our freshwater often adds many different types of dissolved materials to the freshwater supply. This use may lead to pollution of our water resources and cause harm not only to humans but to many life forms, reducing our biodiversity. Most importantly, as our water supplies become scarce, there will be conflicts between individuals who have enough clean water and those who do not. As with any limited resource, this conflict could produce warfare.

Two of the most serious problems facing humans today are shortages of fresh water and the lack of safe drinking water.

Humans use six times as much water today as we did a hundred years ago. As the number of people on Earth continues to rise, our demand for water grows. Also, people living in developed countries use more water per person than individuals in lesser developed countries. This is because most of our activities today, such as farming, industry, building, and lawn care, are all water-intense practices, practices that require large amounts of water.

Droughts occur when for months or years, a region experiences unusually low rainfall. Periods of drought naturally make water shortages worse. Human activities, such as deforestation, can contribute to how often droughts occur. Trees and other land plants add water back into the atmosphere through transpiration. When trees are cut down, we break this part of the water cycle. Some dry periods are normal and can happen anywhere in the world. Droughts are a longer term event and can have serious consequences for a region. Because it is difficult to predict when droughts will happen, it is difficult for countries to predict how serious water shortages will be each year.

Table 16.2:

Water shortages hurt human health, agriculture and the environment. What happens when water supplies run out? In undeveloped regions in the world, people are often forced to move to a place where there is water. This can result in serious conflicts, even wars, between groups of people competing for water.

Water disputes happen in developed countries as well. Water-thirsty regions may build aqueducts, large canals or pathways to import water from other locations. For example, several cities in **arid** regions of the United States import water from the Colorado River. So much water is taken from the river that it can end as just a trickle when it reaches Mexico. Years ago, Mexico could depend on the river supplying water for irrigation and other uses. Today that water resource is gone from importing water upstream.

Some of the biggest legal battles in the United States have been over water rights, including access to the Colorado River. Water disputes may have led to some of the earliest wars known.

Groundwater Zones

Water beneath the land surface occurs in two principal zones, the **unsaturated zone** and the **saturated zone**. In the unsaturated zone, the voids–that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks–contain both air and water. Although a considerable amount of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces.

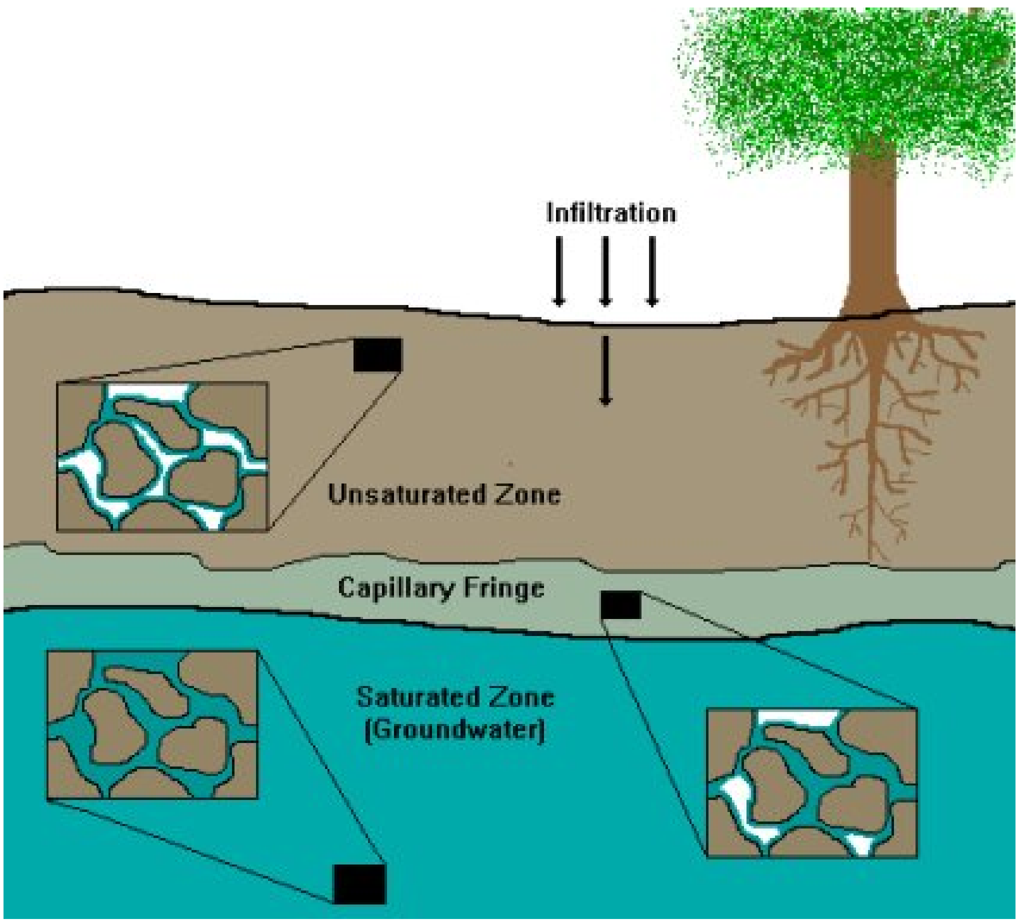
The unsaturated zone is also called the vadose zone. It includes the capillary fringe, the lower part of the unsaturated zone just above the saturated zone, where capillary action pulls water upward from the saturated zone. The capillary fringe can be up to 60 cm thick.

In contrast to the unsaturated zone, the voids in the saturated zone are completely filled with water. Water in the saturated zone is referred to as ground water. The upper surface of the saturated zone is referred to as the water table. Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting ground water to be withdrawn for use. A well is constructed by inserting a pipe into a drilled hole; a screen is attached, generally at its base, to prevent earth materials from entering the pipe along with the water pumped through the screen (US Geological Survey Concepts of Ground Water, Water Table, and Flow Systems)

The water table is not fixed. The height of the water table is controlled by water entering the saturated zone by precipitation, storage in the zone, and the rate that groundwater is pumped from the ground by wells. The water table often slopes toward streams and lakes, and it tends to follow the shape of the land surface.

Groundwater often flows into streams and rivers helping maintain flow in summer and dry periods. It sometimes flows onto the land at springs. About 30% of river flow comes from springs and groundwater.

Table 16.3:



Unsaturated and saturated zones below the earth's surface. The two zones are separated by the capillary fringe zone, which is a few centimeters thick. From Office of Radiation, Chemical & Biological Safety Michigan State University FAQs on Wellhead Protection.

Groundwater Storage Pore Spaces are the voids in rocks, which holds air or water. The volume of pore space, and the size of the pores depends on rock type. Igneous and metamorphic rocks tend to have little or no pore space, although they can have fractures (cracks) that allow water to move through the rock. Sedimentary rocks have pore space that range in size from a fraction of a micrometer in clays to several millimeters in coarse sandstone.

Porosity is the term used to describe the volume of pore space. It is defined to be (volume of pores) divided by (total volume, including pore volume and solid volume). Porosity has a value between 0 and 1 or between 0 and 100%. It controls the volume of water that can be stored in the saturated zone. For more than you ever want to know about porosity read Predicting Sandstone Reservoir System Quality and Example of Petrophysical Evaluation by Dan J. Hartmann (Search and Discovery Article #4005).

Table 16.4: **Porosity of Rock Types**

Granite	0–5%
Shale	< 10%
Sandstone	5–30%
Sand and Gravel (mixed)	22–35%
Sand and Gravel (well sorted)	25–50%
Clay	33–60%

Table 16.5:

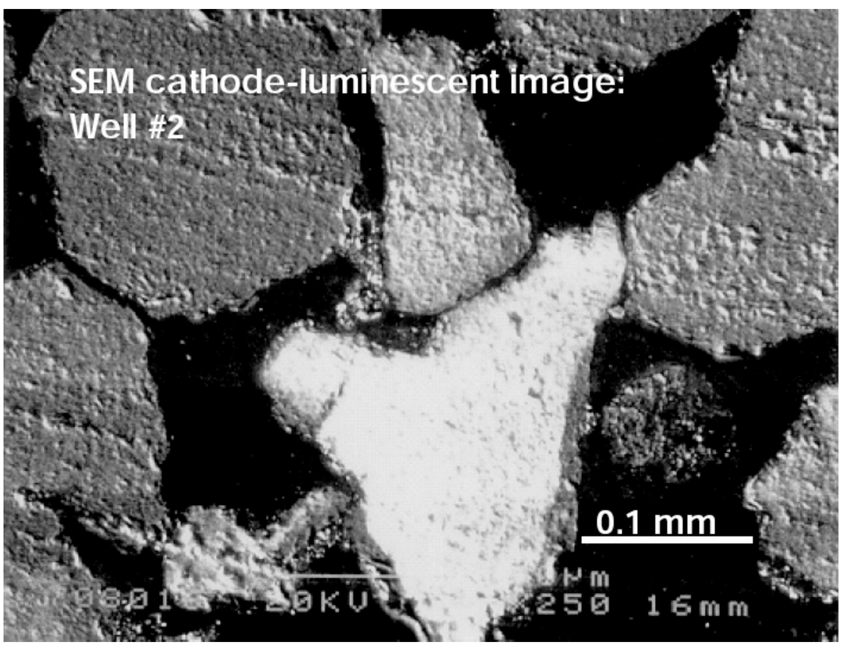


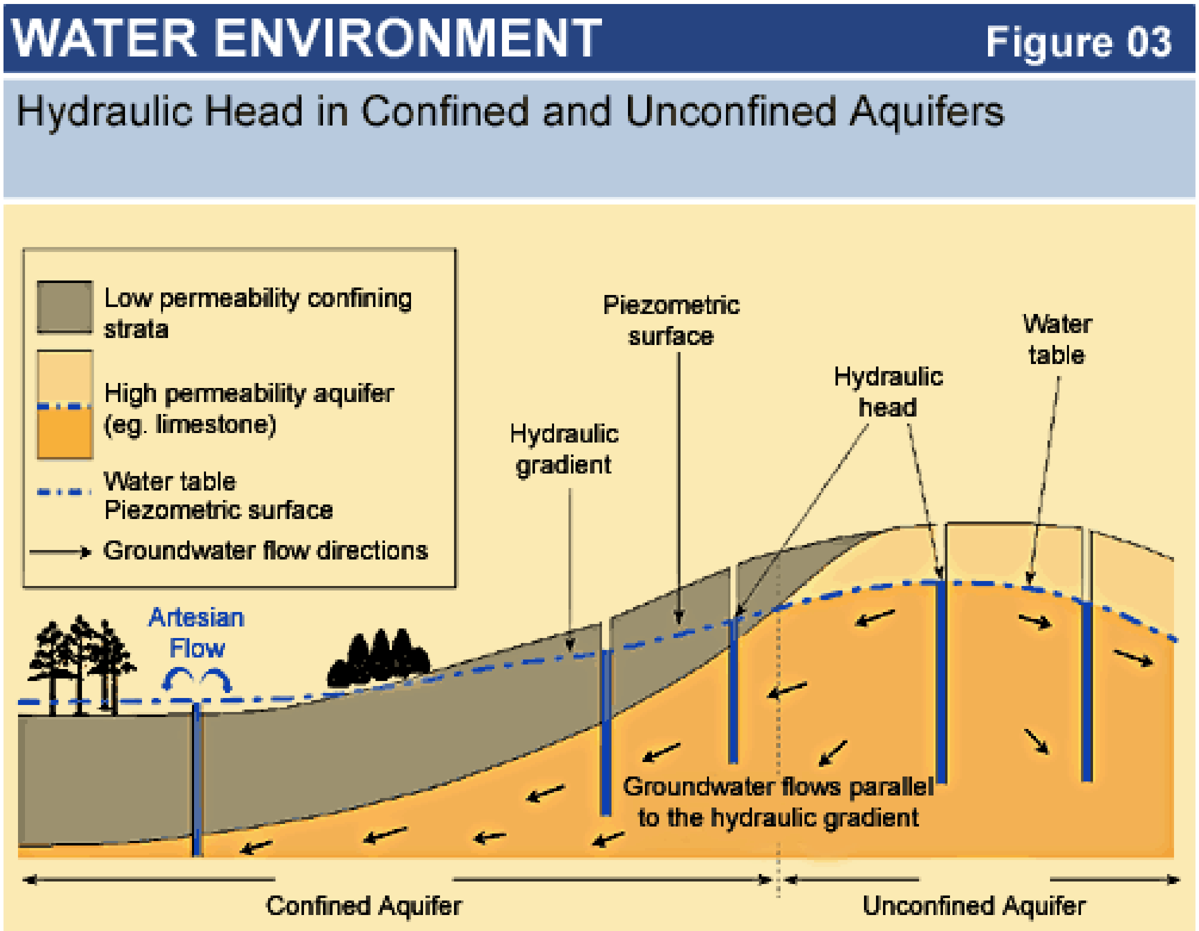
Image of a cross-section through a rock showing pore space and small connections between larger pores. The small connections limit the permeability of the rock. Click on image for a zoom. From National Energy Technology Laboratory web page on Oil & Natural Gas Projects.

Groundwater Flow Rates

Groundwater in the saturated zone flows very slowly downhill from where the water table is high to where it is low. The flow rate depends on:

1. Hydraulic Head. This is the height of the water in a test well relative to a datum such as sea level. For example, it the water level in a test well is 500 feet above sea level, the hydraulic head is 500 feet. If the land surface is 600 feet above sea level, water in the well is 100 feet below the surface. Hydraulic head can be reported in units of height (meters or feet) or pressure (Pa or pounds per square inch).
2. Hydraulic Gradient or Pressure Gradient. This is the hydraulic head (or pressure) at one location minus the hydraulic head (or pressure) at another location divided by the distance between the locations. It is proportional to the slope of the water table. Typically the two points used to calculate the flow are at the recharge zone where water enters the aquifer, and the point where groundwater leaves the aquifer, such as at a spring or well.
3. Hydraulic conductivity (k), which depends on:
    (a) Permeability of the rock or sediment. It depends on:
        i. Size of the pores in the rock, and
        ii. Connection between pores. Pores connected by very small, narrow channels have low permeability.
    (b) Density of the fluid, and
    (c) Viscosity of the fluid.
    (d) The dimensions of k are meters per second.
    (e) k has a very wide range of values, ranging from 10^{-1} m/s for gravels to 10^{-8} m/s for silt and clay.
    (f) Because density and viscosity do not vary much, the variability of hydraulic conductivity is due almost entirely to variability of the permeability of the different rock types.

Table 16.6:



From University of Leeds Goodquarry web page on The Water Environment.

Sandstone has high porosity and high permeability. Clay has high porosity and very low permeability. Fractures greatly increase permeability Good aquifers such as sand, gravel, sandstone, porous limestone, and highly fractured bedrock have high porosity and permeability. Poor aquifers, such as shale, mudstone, clay, or unfractured igneous and metamorphic rock, have low porosity or permeability.

Flow Rate (V) is calculated from Darcy's Equation (Sometimes called Darcy's Law).

> V = (k) (head) / (distance) = k (hydraulic gradient) where k = hydraulic conductivity.

Flow rates in aquifers tend to be slow. 5–10 feet/year for clays, 3 feet/day for sorted sand, and up to 1000 feet/day or more for karsts. The flow rate in our local sand aquifer is roughly 1 m/yr.

> Karst is a special type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite. Karst regions contain aquifers that are capable of providing large supplies of water. More than 25 percent of the world's population either lives on or obtains its water from karst aquifers. In the United States, 20 percent of the land surface is karst and 40

percent of the groundwater used for drinking comes from karst aquifers. Natural features of the landscape such as caves and springs are typical of karst regions. Karst landscapes are often spectacularly scenic areas. Examples include the sinkhole plains and caves of central Kentucky, the large crystal-clear springs of Florida, and the complex, beautifully decorated caves of New Mexico [and theEdwards Aquifer System in Texas]. From Karst Waters Institute.

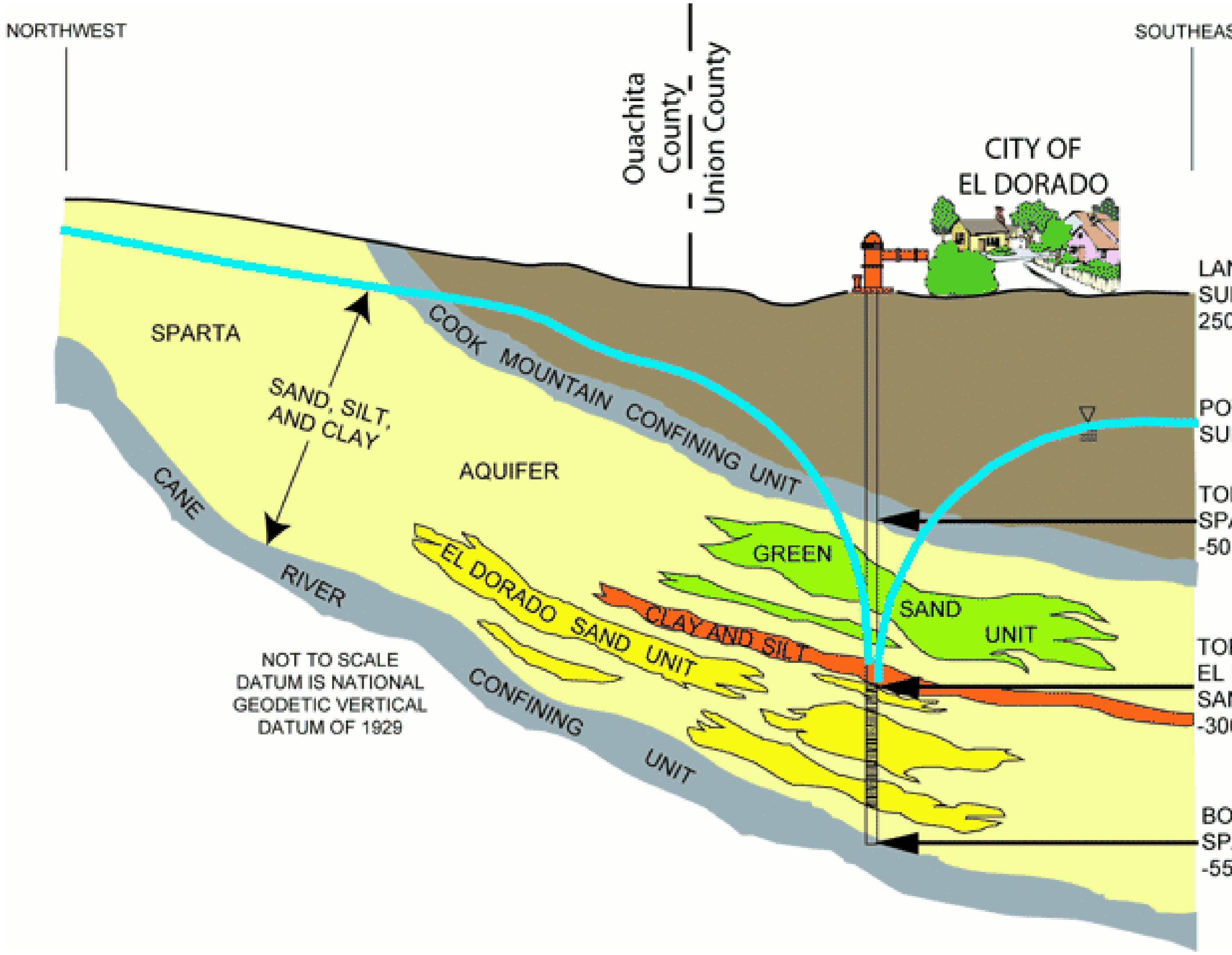
Table 16.7:

From Karst Waters Institute,  after Davies and others, 1984, U. S. Geological Survey, National Atlas, Engineering Aspects of Karst.

Aquifer Systems

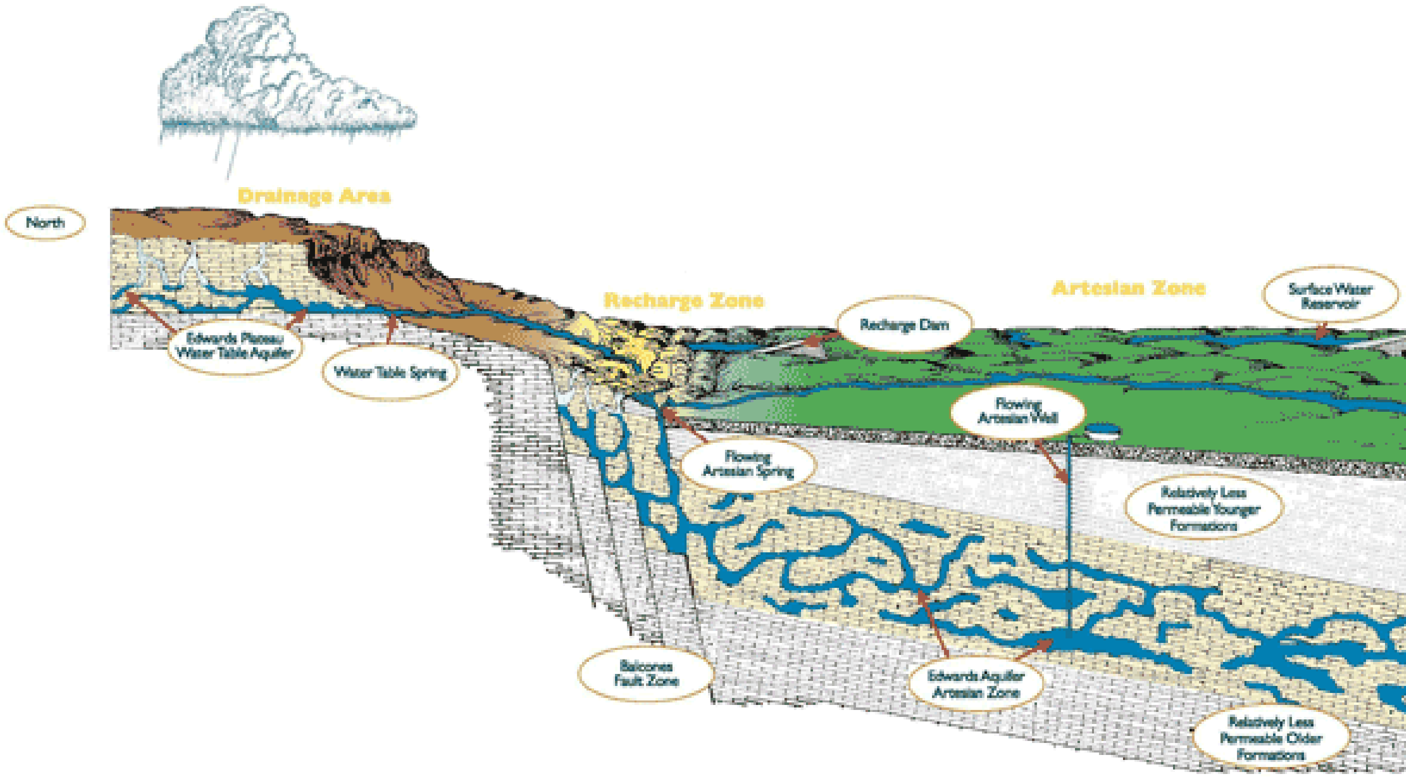
The infiltration of groundwater through the unsaturated zone (vadose zone) into the saturated zone is called recharge. The area where water enters the aquifer is called the recharge zone. As water moves through the aquifer, it is confined by layers of less permeable rock, such as clays or silts, called aquitards, which can split the aquifer into separate units. An aquifer system consists of aquifers and aquitards. An aquifer that is confined above and below by an aquitard is called a confined aquifer (see the figure above and below for examples).

Table 16.8:



Cross section of the Sparta Aquifer in southern Arkansas, showing Cook Mountain and Cane River aquitards, and the cone of depression at the El Dorado municipal well. The recharge zone is on the far left where the aquifer (yellow) outcrops. The aquifer that supplies College Station, Texas (see case study below) is similar to this, with the aquifer being the Simsboro Sand in the Carrizo-Wilcox formation. From US Geological Survey web page on Reports and Fact Sheets on the Sparta.

Table 16.9:



Cross section of the Edwards Aquifer, Texas. It is the primary source of water for approximately 1.7 million people. Rain falling in the drainage area soaks into the limestone of the plateau (a karst region) forming spring-fed streams. The recharge zone is located in an area geologically known as the Balcones Fault Zone. In the recharge zone porous and permeable Edwards Limestone is exposed at the surface and provides a path for water to reach the artesian zone. Recharge is water that enters the aquifer through features such as fractures, sinkholes and caves. The artesian zone is a complex network of interconnecting spaces varying from microscopic pores to open caverns in the karst. A larger image is available from the Edwards Aquifer Authority. From Edwards Aquifer Authority.

Good Aquifers

Good aquifers provide adequate quantities of high quality water.

1. The quality of the water depends on water chemistry discussed below.
2. The quantity of water available from an aquifer depends on:
   (a) Porosity - determines amount of groundwater storage.
   (b) Size of aquifer - thickness and area.
   (c) Permeability - affects recharge rate, ability to pump.

Artesian Wells

If the hydraulic head (potentiometric surface) is higher than the land surface, water pressure in a well is so high that water rises to the surface without the need to pump the water. This is an artesian well. See the figure for hydraulic head.

Overpumping From Aquifers and Groundwater Mining

Aquifers are such a convenient source of water that it is easy for cities, irrigation districts, and farmers to pump more water from the aquifer than recharge can supply when averaged over a period of many years. This is called groundwater mining. Almost everywhere in the world pumping exceeds recharge. Eventually the wells will run dry. But before this happens, over pumping leads to to reduction of water level in the wells and sometimes to land subsidence.

Cone of Depression When water is pumped from an aquifer faster than the water can be reach the well, the hydraulic head is depressed around the well, recovering to original values at some distance from the well. This is the depressed potentiometric surface (surface of constant hydraulic head) drawn with a blue line in the sparta-aquifer figure above. If the aquifer is unconstrained, the water table coincides with the potentiometric surface, and it is pulled down in a cone of depression centered on the well.

If the cone of depression reaches another well, it may run dry. If it reaches nearby streams, water may no longer enter the stream and the stream could dry up.

An Example of Groundwater Mining: The Ogallala Aquifer

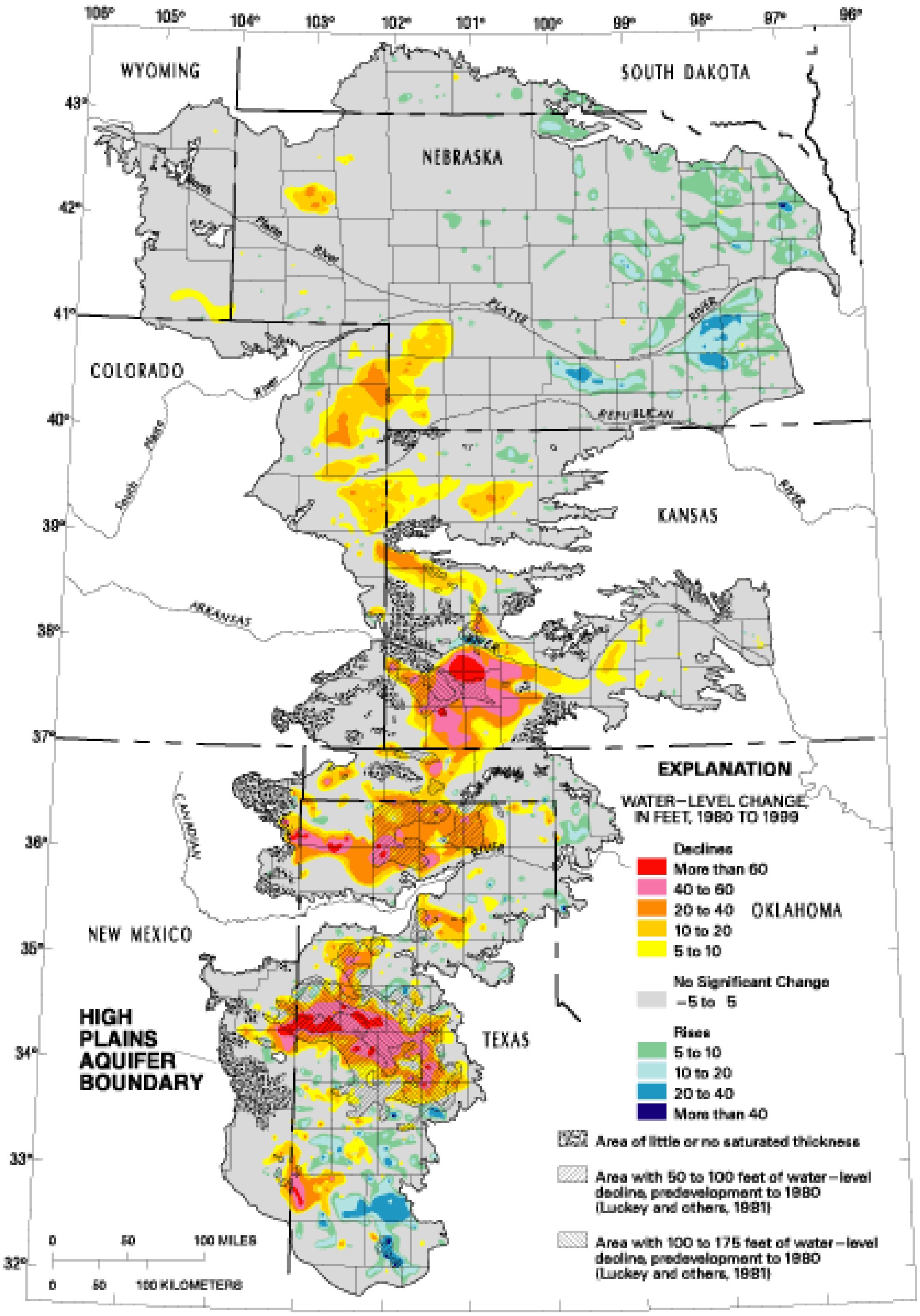
The Ogallala Aquifer (High-Plains Aquifer) is a good example of groundwater mining. The aquifer is the largest in the US with an area of 450,000 km^2. It occurs in Tertiary and Quaternary sediments, and the aquifer thickness averages 60 m, and is as great as 180 m. Pumping from the aquifer increased rapidly after WWII due to (Guru and Horne, 2000):

1. Efficient deep-well pumps,
2. Low-cost energy to run gasoline or natural-gas engines,
3. Inexpensive aluminum piping,
4. Center-pivot sprinklers and other watering technologies. They produced the circles in the image of Finney County. A well and center-pivot sprinkler is in the center of each circle.
5. New management skills, and
6. An increased scale of operation.

Now, nearly nearly 170,000 wells pump around 2 x 10^{10} cubic meters per year (19 million acre feet) to irrigate > 65,000 km^2 of land. As a result:

1. Water table has declined. 3 to 15 m decline is common, and in some regions the decline is greater than 60 m. Parts of the aquifer are already depleted in Kansas. The average decline was 3.7 m (11.9 feet) from predevelopment times to 2000 and 1.0 m (3.2 feet) from 1980 to 1999.
2. Irrigated acreage is declining.
3. Cost of pumping is increasing.

Table 16.10:



Change of depth of water table in the Ogallala Aquifer between 1980 and 1999. From McGuire (2001).

An Example of Land Subsidence: Brownwood Subdivision, Texas Water pressure in the pores of an aquifer helps support the weight of the overlying rocks or sediments. As water is withdrawn and the hydraulic head drops, the rock and sediment is compacted and the land surface subsides. Excessive pumping of water from beneath Houston, Texas has led to widespread subsidence and the destruction of the once prosperous Brownwood subdivision.

About 500 upper-income homes were built in Brownwood, many were for executives of Humble Oil Company. Pumping of groundwater at a rate exceeding 540 million gallons per day in the Houston Area led to subsidence of a large area between Baytown and Houston. Brownwood, which was originally 10 feet above sea level, sank as much as 9 feet between 1915 and 1978.

> Brownwood subdivision was once the most elite residential section of Baytown. Perched on a bay fronting the Houston Ship Channel, it featured the expensive homes of executives and engineers for the nation's largest petrochemical complex, which had sprouted nearby. Excessive use of groundwater – both by industry and the municipalities that grew around it – caused the subdivision in the 1960s to begin to sink into the bay, slowly at first. Eventually, Brownwood was destroyed almost completely by Hurricane Alicia in 1983. Today, the abandoned peninsula has returned to Nature, partly on its own and partly through the efforts of a marshland restoration project funded by chemical companies under court order. From Houston Wet.

Table 16.11:

Left: Suzanne Brown and children at her in-law's house, Brownwood subdivision, 1968. Courtesy J.T. and Suzanne Brown. Right: House in Brownwood subdivision, outside perimeter road, 1976. Courtesy Brownwood Civic Association Archives. Both from Houston Wet Scrapbook.

16.6 Water Quality Problems

Scarcity of Safe Drinking Water

The next time you get water from your faucet, imagine life in a country that cannot afford the technology to treat and purify water. What would it be like if your only water came from a polluted river where sewage was dumped? Your only choice would be to drink polluted water. One fifth of all people in the world, more than 1.1 billion people, do not have access to safe water for drinking, personal cleanliness and domestic use. Unsafe drinking water can carry many disease-causing agents, such as infectious bacteria, toxic chemicals, radiological hazards, and parasites.

One of the leading causes of death worldwide is waterborne disease, disease caused by unsafe drinking water. It is also the leading cause of death for children under the age of five. Many children die when they only have unsafe drinking water and lack of clean water for personal hygiene. About eighty-eight percent of all diseases are caused by drinking unsafe water. At any given time, half of the world's hospital beds are occupied by patients suffering from a waterborne disease. The water you get from a faucet is safe because it has gone through a series of treatment and purification processes to remove contaminants.

Water pollution, especially from **nonpoint sources** or runoff, threatens vital freshwater and marine resources in the U.S. and throughout the world. A single example dramatically illustrates the potential for disruption of natural cycles and loss of biodiversity. Runoff of fertilizers applied to vast expanses of agricultural land and other sources such as wastewater have led to what ecologists say is a doubling of the amount of nitrogen available to plants and animals, and that amount could increase by another 60% by 2050. At first glance this may seem like a benefit to life, but it is not. Especially in aquatic ecosystems, excessive nutrients lead to overgrowth of algae, creating **algal blooms**. Some species are toxic in themselves, but more often, this **eutrophication** - literally, ‘‘feeding too well” - leads to such high levels of respiration (recall that photosynthesizers must respirate – especially at night!) that dissolved oxygen levels plummet, resulting in the death of fish and other species. Death results in decomposition and further nutrient input – compounding the problem. Eutrophication threatens one of the most diverse habitats on earth – coral reefs, which cover just 1% of the earth's surface yet harbor 25% (over 4000) - of marine fish species. Adapted to low-nutrient environments and characterized by tight nutrient cycles, reefs in the pathway of excess nutrient runoff from agriculture and development become overgrown with algae, which block light from coral polyps. The Nature Conservancy predicts that 70% of Earth's coral reefs will have disappeared by 2050 if current rates of destruction continue.

Among the most devastating consequences of eutrophication are at least 146 **dead zones**, where low oxygen levels caused by eutrophication have extinguished all ocean life. The most notorious extends into the Gulf of Mexico at the mouth of the Mississippi River, which brings fertilizer runoff from the U.S. corn belt (**Figure ??**). In July of 2007, this dead zone covered an area of ocean the size of New Jersey and affected shrimp and fishing industries as well as countless species of marine organisms. Interestingly, a similar zone in the Black Sea disappeared between 1991 and 2001, after political changes in the Soviet Union and Eastern Europe made fertilizers too expensive to use for most agriculture. Unfortunately, most are growing, and the nitrogen cycle disruption affects many bodies of freshwater throughout the world, as well.

Finding safe drinking water poses further challenges. What does it take for a country to provide its people with access to safe drinking water? It takes sophisticated technology to purify water, which removes harmful substances and **pathogens**, disease-causing organisms. Most developing countries lack the finances and the technology needed to supply their people with purified drinking water.

Water resources are so valuable, that wars have been fought over water rights throughout history. In many cases, water disputes add to tensions between countries where differing national interests and withdrawal rights have been in conflict (Figure 21.15).

Some of today's greatest tensions are happening in places where water is scarce. Water disputes are happening along 260 different river systems that cross national boundaries including water disputes between:

- Iraq, Iran, and Syria
- Hungary and Czechoslovakia
- North and South Korea
- Iran and Syria
- Israel and Jordan
- Egypt and Ethiopia

International water laws, such as the Helsinki Rules, help interpret water rights among countries.

Water Quality Components

The quality of well water depends on the total amount and type of dissolved solids, gases, and contaminants. Dissolved solids depend on the type of rock in the aquifer, and how long the water was in the aquifer. Water that contains high amounts of Ca^{2+} and/or Mg^{2+} is called hard water. Soft water may contain Na^{+} or other minerals. Water may also have a bad smell due to hydrogen sulfide, it may contain reactive minerals such as pyrite (FeS_2), or it may turn sinks red due to dissolved iron (Fe^{2+}).

Water flowing through limestone tends to be high in dissolved calcium bicarbonate ($CaHCO_3$). It is hard, with moderate amounts of anhydrite ($CaSO_4$). If the limestone has shale aquitards, the calcium bicarbonate is changed to sodium bicarbonate ($NaHCO_3$), and the water is soft, with moderate to high total dissolved solids.

Water flowing through cracks in igneous rocks tends to have low concentrations of total dissolved solids, and it is sometimes called mountain spring water.

Water pollution can make our current water shortages even worse than they already are. Imagine that all of your drinking water came from a river polluted by industrial waste and sewage. In undeveloped countries throughout the world, raw sewage is dumped into the same water that undeveloped people drink and bathe in. Without the technology to collect, treat and distribute water, people do not have access to safe drinking water. Throughout the world, more than 14,000 people die every day from waterborne diseases, like cholera which is spread through polluted water.

Even in developed countries that can afford the technology to treat water, water pollution affects human and environmental health.

Water pollution includes any contaminant that gets into lakes, streams, and oceans. The most widespread source of water contamination in undeveloped countries is raw sewage dumped into lakes, rivers and streams. In developed countries, the three main sources of water pollution are:

- Agriculture, including fertilizers, animal waste and other waste, pesticides, etc.
- Industry, including toxic and nontoxic chemicals
- Municipal uses, including yard and human waste

Drinking Water Quality

The Safe Drinking Water Act (SDWA) [enacted in 1974 and amended in 1986, 1991, and 1996] authorizes the Environmental Protection Agency to set national health-based standards for drinking water to protect against both naturally-occurring and man-made contaminants that may be found in drinking water. US EPA, states, and water systems then work together to make sure that these standards are met. ... Originally, SDWA focused primarily on treatment as the means of providing safe drinking water at the tap. The 1996 amendments greatly enhanced the existing law by recognizing source water protection, operator training, funding for water system improvements, and public information as important components of safe drinking water. This approach ensures the quality of drinking water by protecting it from source to tap. Environmental Protection Agency Basic Information on Safe Drinking Water Act.

Under changes made in the 1986 Safe Drinking Water Act amendments, the EPA required all public water systems to monitor for

1. 16 inorganic, non-carbon compounds such as nitrates, arsenic, fluoride, selenium.
2. 54 carbon-containing contaminants for which maximum contaminant levels (MCLs) have been established.
3. The number and levels of contaminants is constantly changing as new problems are discovered. Currently, the EPA has developed MCLs for:
   - (a) 7 types of bacterial or viral microorganisms;
   - (b) 7 standards for disinfectants like chlorine or disinfectant products like bromate;
   - (c) 16 inorganic compounds;
   - (d) 54 carbon-based compounds, and
   - (e) 4 radionuclides.
4. In addition, the EPA has National Secondary Drinking Water Regulations in place for 15 compounds or contaminants, including chloride, sulfate and pH, which can cause cosmetic – skin discoloration – or aesthetic effects, such as taste, odor or color.
5. The 1996 Amendments to the Safe Drinking Water Act require monitoring of other "unregulated" carbon-based chemicals for which levels have not yet established. Currently, some 35 contaminants are on the list, including Acetochlor, Diazinon and Perchlorate.

All municipal water agencies must test regularly for all the contaminants listed above, and to provide report the results to everyone who uses their water. The goal is to remove contaminants, but not naturally occurring minerals, many of which are essential for good health, including many trace elements such as selenium that are toxic in high concentrations.

> According to the U.S. National Academy of Sciences (1977) there have been more than 50 studies, in nine countries, that have indicated an inverse relationship between water hardness and mortality from cardiovascular disease. That is, people who drink water that is deficient in magnesium and calcium generally appear more susceptible to this disease.
>
> The U.S. National Academy of Sciences has estimated that a nation-wide initiative to add calcium and magnesium to soft water might reduce the annual cardiovascular death rate by 150,000 in the United States. From Foster (1994).

16.7 Water Pollution

Residents in cities and many rural homes use groundwater for drinking and other household purposes. At the same time, groundwater is contaminated by many sources. How dangerous are pollutants in drinking water, where do they come from, and will they increase in the future?

Groundwater Contamination is the detrimental alteration of the naturally occurring physical, thermal, chemical, or biological quality of groundwater. Further, groundwater contamination, for purposes of inclusion of cases in the public files and the joint groundwater monitoring and contamination report, shall be limited to contamination reasonably suspected of having been caused by activities of entities under the jurisdiction of the agencies identified in the Texas Water Code §26.406, TGPC rules, and subsequent legislative amendments. Groundwater contamination may result from many sources, including current and past oil and gas production and related practices, agricultural activities, industrial and manufacturing processes, commercial and business endeavors, domestic activities, and natural sources that may be influenced by, or may result from, human activities. From Texas Groundwater Protection Committee (2005)

Sources of Contamination:

Groundwater is contaminated by many activities such as those shown here.

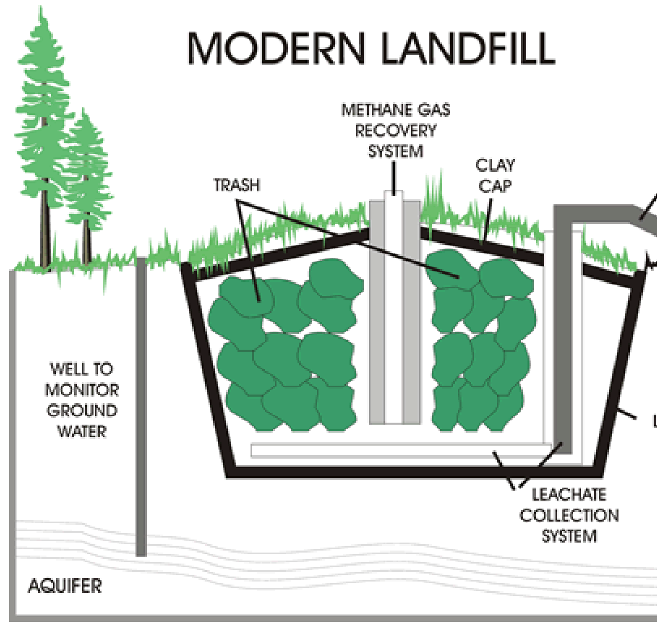
Sources of groundwater contamination. Click on the image for a zoom. From US Environmental Protection Agency, Safe Drinking Water - Protecting America's Public Health Poster.

A. Landfills and Hazardous Waste Facilities.

Texans alone dispose of approximately 30 million tons of municipal solid waste (durable and non durable goods, containers, food scraps, yard waste, inorganic waste, sludge from water and wastewater treatment facilities, septic tanks, construction and demolition debris) per year. 63% is residential. 37% is commercial and institutional. In 2005, there were 186 active landfills in Texas. They received 29.67 million tons of waste. Excluding construction waste, the per capita disposal rate in Texas 5.5 pounds per person per day. In 2005, U.S. residents, businesses, and institutions produced more than 245 million tons, which is approximately 4.5 pounds of waste per person per day. Almost all goes into landfills. (Texas Environmental Almanac and EPA Municipal Solid Waste).

Landfills contaminate groundwater when rain water leaks into aquifers below the landfill. Many early landfills did not have liners to trap rainwater that percolates through the landfill, and some newer landfills have liners that leak. The percolating water leaches toxic chemicals from batteries, broken fluorescent bulbs, electronic equipment, discarded household chemicals, and paints and solvents. Although landfills now prohibit toxic waste, and they are carefully regulated to prevent leakage to groundwater, many older sites are unlined and leak.

Table 16.12:



Left: A municipal landfill. Right: Design of a modern landfill. Left from Aircraft Owners and Pilots Association. Right from Energy Information Administration A Modern Landfill.

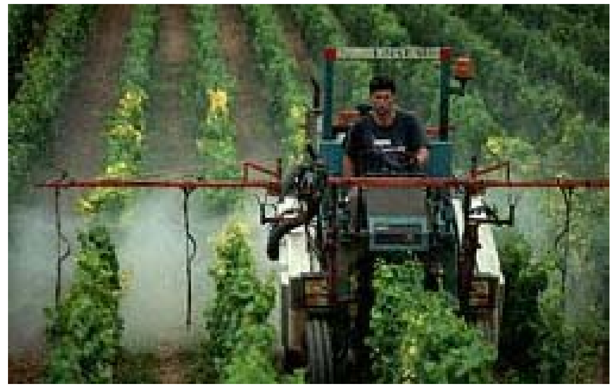
B. Agriculture

Agriculture includes crops, livestock, and poultry farming. Most agricultural contaminants are carried by runoff that carries fertilizers, pesticides, and animal waste into nearby waterways (Figure 21.18). Soil and silt erosion also contribute to surface water contamination.

Animal wastes expose humans and the environment to some of the most harmful disease causing organisms or pathogens. These include bacteria, viruses, protozoa, and parasites. Pathogens are especially harmful to humans, because they can cause many illnesses including typhoid and dysentery as well as minor respiratory and skin diseases.

Extensive herbicide use in agricultural areas (accounting for about 70 percent of total national use of pesticides) has resulted in widespread occurrence of herbicides in agricultural streams and shallow ground-water. The highest rates of detection for the most heavily used herbicides—atrazine, metolachlor, alachlor, and cyanazine—were found in streams and shallow ground water in agricultural areas. Insecticides were frequently detected in some streams draining watersheds with high insecticide use but were less frequently detected in shallow ground water because most insecticides are applied at lower levels than herbicides and tend to sorb onto soil or degrade quickly after application. From USGS Water-Quality Patterns In Agricultural Areas

Table 16.13:



Application of agricultural pesticides. Left: By a crop dusted. Right: From the ground. From Colorado State University Environmental Health Advanced Systems Laboratory

Every year you can see **dead zones**, hundreds of kilometers of ocean without fish or plant life (Figure 21.19). These dead zones occur in the Gulf of Mexico and other river delta areas due to water polluted with fertilizers. In 1999, a dead zone in the Gulf of Mexico reached over 7,700 square miles.

C. Mining

Mining wastes include waste generated during the extraction, beneficiation, and processing of minerals. Extraction is the first phase of hard rock mining which consists of the initial removal of ore from the earth. Beneficiation is the initial attempt at liberating and concentrating the valuable mineral from the extracted ore. This is typically performed by employing various crushing, grinding and froth flotation techniques. Mineral processing operations generally follow beneficiation and include techniques that often change the chemical composition of the ore or mineral, such as smelting (iron and steel), electrolytic refining (aluminum) and acid attack or digestion. Copper and gold mines comprise 80% of the non-fuel facilities in the United States. They discard 90% to 99.99% of the mined rock, generating 1.3 gigatons of waste. From Environmental Protection Agency web pages on mining.

Coal mines are another major source of contaminants. When pyrite rocks associated with coal mining are exposed to oxygen they are oxidized to generate acid mine drainage. The waste then flows into streams and infiltrates into aquifers.

A complex series of chemical weathering reactions are spontaneously initiated when surface mining activities expose spoil materials to an oxidizing environment. The reactions are analogous to "geologic weathering" which takes place over extended periods of time (i.e., hundreds to thousands of years) but the rates of reaction are orders of magnitude greater than in "natural" weathering systems. The accelerated reaction rates can release damaging quantities of acidity, metals, and other soluble components into the environment. For example, the overall pyrite reaction series [which occurs in high-sulfur coal mines] is among the most acid-producing of all weathering processes in nature. From US Department of the Interior Factors controlling acid mine drainage formation.

Table 16.14:


Left: Pollution due to acid mine drainage in the Blackwater River of West Virginia. (From US Department of the Interior).Right: Water collecting in the open-pit Adams Mine, an open-pit iron mine in Ontario, Canada.Right: From Adams Mine Landfill Proposal.

D. Above Ground and Underground Storage Tanks

Gasoline stations, dry cleaners, and other industrial establishments store large quantities of liquids in tanks. Some are above ground, some are below ground. Homes is cold areas store heating oil in underground tanks or in basement tanks. Underground tend to cause groundwater contamination because small leaks often go undetected.

Nearly one out of every four underground storage tanks in the United States may

> now be leaking, according to the U.S. Environmental Protection Agency. If an underground petroleum tank is more than 20 years old, especially if it's not protected against corrosion, the potential for leaking increases dramatically. Newer tanks and piping can leak, too, especially if they weren't installed properly. Even a small gasoline leak of one drop per second can result in the release of about 400 gallons of gasoline into the groundwater in one year. Even a few quarts of gasoline in the groundwater may be enough to severely pollute a farmstead's drinking water. At low levels of contamination, fuel contaminants in water cannot be detected by smell or taste, yet the seemingly pure water may be contaminated to the point of affecting human health. Petroleum fuels contain a number of potentially toxic compounds, including common solvents such as benzene, toluene and xylene, and additives such as ethylene dibromide (EDB) and carbon-based lead compounds. EDB is a carcinogen (cancer-causing) in laboratory animals, and benzene is considered a human carcinogen. From University of Missouri web page on Assessing the Risk of Groundwater Contamination From Petroleum Product Storage.

The EPA identified over 460,000 leaking underground storage tanks up to September 30, 2006. Steady cleanup work has progressed for over a decade and more than 350,000 contaminated sites have been cleaned up. The main concern now is contamination by methyl tertiary-butyl ether MTBE. The additive, or other additives with similar ability to oxygenate fuels, is required by the EPA to help reduce carbon monoxide emissions from cars in cold weather.

Table 16.15:

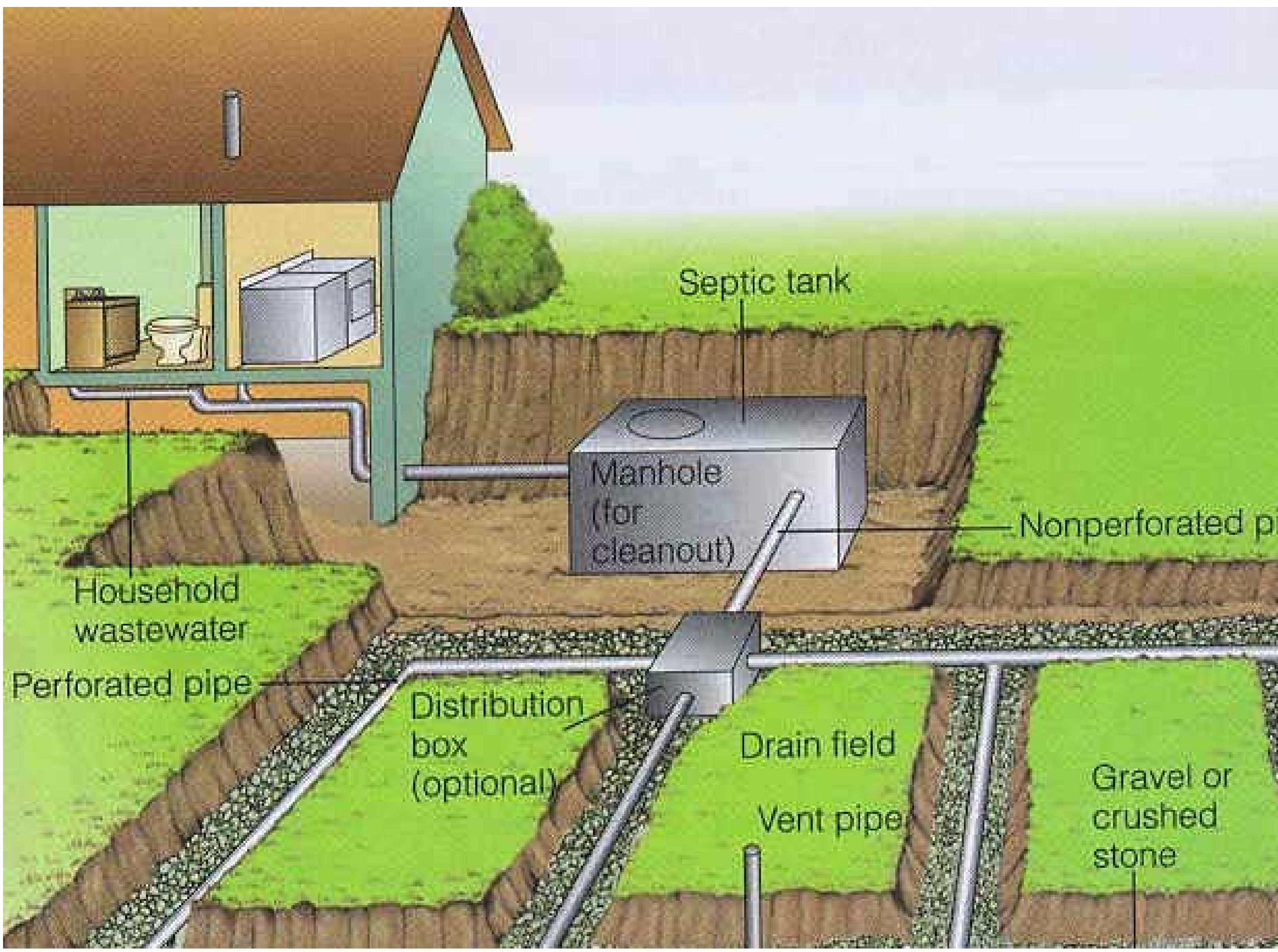
Gasoline storage tank being removed from site. From Virginia TechGroundwater Pollution Primer.

E. Septic Systems

Homes not connected to municipal sewer systems usually use septic systems to dispose of wastewater from toilets and drains. Waste water drains first into a septic tank where solids are separated from the liquid. Light solids such as fats rise to the surface, heavy solids sink to the bottom. The light solids remain until the tank is cleaned. Some of the heavy solids are decomposed by bacteria, some remain until the tank is cleaned. Relatively clear water from the tank drains into a field of pipes, the drain field or leach field, which slowly leak water into the ground. Most percolates downward and enters the water table, some is taken up by plants, some evaporates. The water is cleaned by natural remediation processes.

Water discharged into the ground includes nitrates and phosphorus which can contaminate aquifers or nearby streams.

Table 16.16:



From Thurston County (Washington State) Public Health & Social Services Department web page on Inspecting Your Septic Tank.

F. Oil, Gas, and Industrial Injection Wells

An injection well is an artificial excavation or opening in the ground made by digging, boring, drilling, jetting, driving, or some other method, and used to inject, transmit, or dispose of industrial and municipal waste or oil and gas waste into a subsurface stratum; or a well initially drilled to produce oil and gas which is used to transmit, inject, or dispose of industrial and municipal waste or oil and gas waste into a subsurface stratum; or a well used for the injection of any other fluid; but the term does not include any surface pit, surface excavation, or natural depression used to dispose of industrial and municipal waste or oil and gas waste." All injection wells are regulated by either TCEQ (the commission in the Act) or the Railroad Commission of Texas TCEQ (RRC). From Texas Commission on Environmental Quality web page on Injection Wells: Am I Regulated?

Table 16.17:

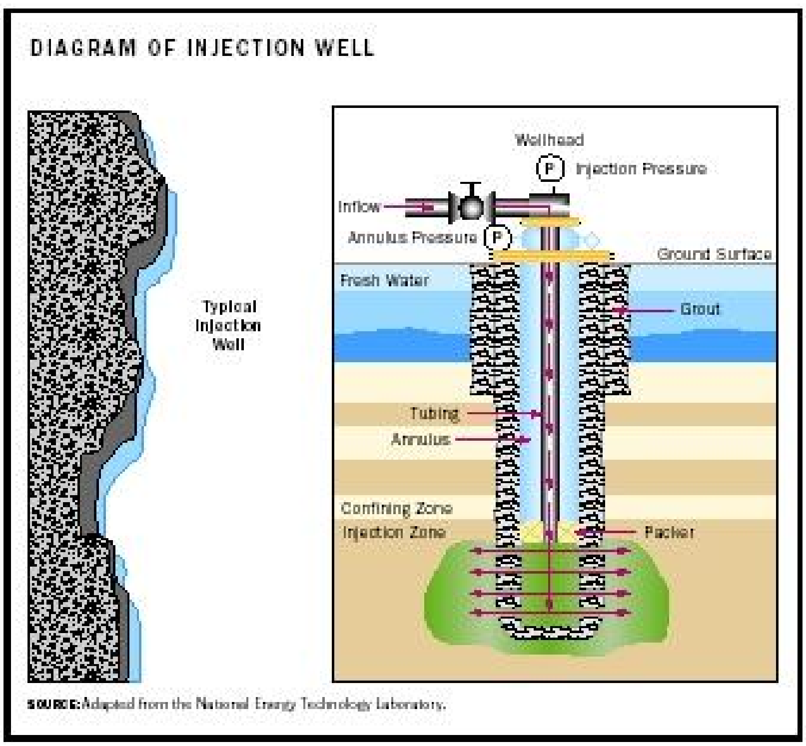


Diagram of an injection well. From Pollution Issues

The US Environmental Protection Agency defines five classes of injection wells, all of which have important uses.

1. **Deep Wells Used to Inject Hazardous and Non-hazardous Waste Deep Below the Surface**. EPA Class I Injection of hazardous waste into deep wells began in the United States in the

1960s. Class I wells are also used to dispose of non-hazardous industrial, low-radiation and municipal wastes. Because 89 % of the hazardous waste that is disposed of on land is disposed through Class I wells, they are the most strictly regulated type of well.

2. **Oil and Gas Injection Wells.** EPA Class II This is the most common type of injection well. The oil and gas production industry accounts for a large proportion of the fluids injected into the subsurface. Typically, when oil and gas are extracted, large amounts of salt water (brine) are also brought to the surface. This salt water can be very damaging if it is discharged into surface water. http://www.epa.gov/safewater/uic/classii.html
3. **Mining Wells.** EPA Class III Wells are used to mine salt, sulfur, and uranium. A number of minerals are mined by using injection wells. In general the technology involves the injection of a fluid that contacts an ore which contains minerals that dissolve in the fluid. When the fluid is nearly saturated with components of the ore it is pumped to the surface where the mineral is removed from the fluid. More than 50% of the salt used in the US is obtained this way.
4. **Shallow Hazardous and Radioactive Injection Wells.** EPA Class IV These wells are prohibited unless the injection wells are used to inject contaminated ground water that has been treated and is being injected into the same formation from which it was drawn. http://www.epa.gov/safewater/uic/classiv.html
5. **Shallow Injection Wells.** Class V wells inject non hazardous fluids into or above an aquifer. They are typically shallow, on-site disposal systems, such as floor and sink drains that discharge into dry wells, septic systems, leach fields, and similar types of drainage wells. The two most numerous types of Class V wells are storm water drainage and large capacity septic systems. Large cesspools and shallow waste disposal systems that receive or have received fluids from vehicular repair or maintenance activities, such as auto body or automotive repair, car dealerships, or other vehicular repair work, are now prohibited. Some Class V wells inject surface water to recharge aquifers, to control land subsidence, and to limit salt-water intrusion provided the injected water does not endanger underground sources of drinking water.

Types of Contaminants from injection wells:

Methyl Tertiary-Butyl Ether MTBE

> Methyl tertiary-butyl ether (MTBE) is produced in very large quantities (over 200,000 barrels per day in the U.S. in 1999) and is almost exclusively used as a fuel additive in motor gasoline. It is one of a group of chemicals commonly known as "oxygenates" because they raise the oxygen content of gasoline. At room temperature, MTBE is a volatile, flammable and colorless liquid that dissolves rather easily in water. MTBE has been used in U.S. gasoline at low levels since 1979 to replace lead as an octane improver (helps prevent the engine from "knocking"). Since 1992, MTBE has been used at higher concentrations in some gasoline to fulfill the oxygenate requirements set by Congress in the 1990 Clean Air Act Amendments. Oxygen helps gasoline burn more completely, reducing harmful tailpipe emissions from motor vehicles. In one respect, the oxygen dilutes or displaces gasoline components such as aromatics (e.g., benzene) and sulfur. In another, oxygen optimizes the oxidation during combustion. Most refiners have chosen to use MTBE over other oxygenates primarily for its blending characteristics and for economic reasons. The Clean Air Act Amendments of 1990 (CAA) require the use of oxygenated gasoline in areas with unhealthy levels of air pollution. The CAA does not specifically require MTBE. Refiners may choose to use other oxygenates, such as ethanol. From EPA web page on MTBE in Fuels.
>
> The health effects of MTBE are not well understood. When inhaled in high concentrations, it causes cancer in some research animals. There is little data on its effects

when humans ingest the chemical. EPA's Office of Water has concluded that available data are not adequate to estimate potential health risks of MTBE at low exposure levels in drinking water but that the data support the conclusion that MTBE is a potential human carcinogen at high doses. The EPA reviewed the available information on health effects in a 1997 advisory and stated that there is little likelihood that MTBE concentrations between 20 and 40 ppb in drinking water would cause negative health effects. The EPA Drinking Water Advisory recommends, but does not require, that concentrations be below 20 ppb in drinking water.

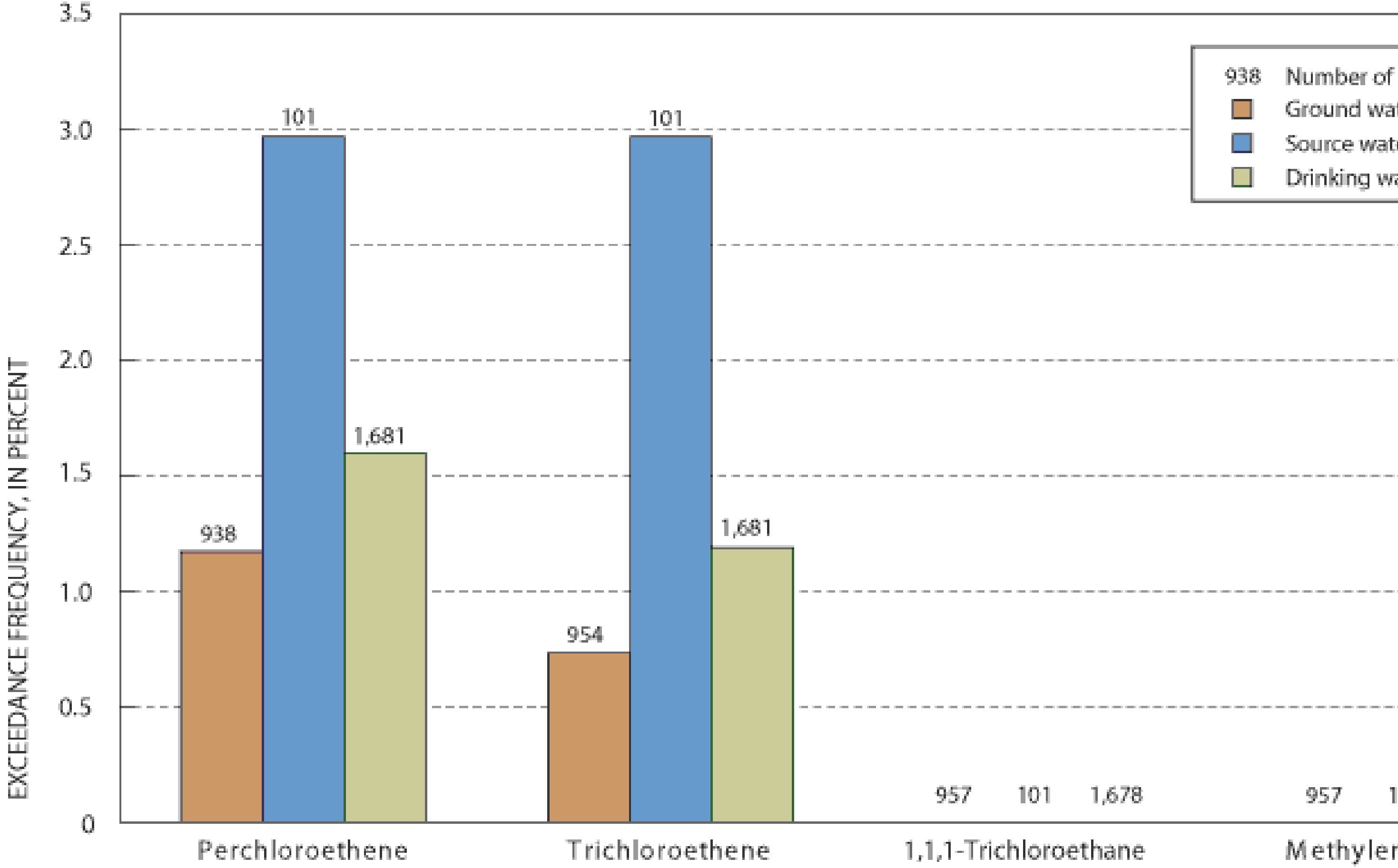
Chlorinated Solvents

Chlorinated solvents are volatile organic (carbon-based) compounds (VOCs) that contain chlorine. In general, chlorinated solvents have low water solubility and high volatilities and densities relative to other VOCs. They are used in aerospace and electronics industries, dry cleaning, manufacture of foam, paint removal/stripping, manufacture of pharmaceuticals, metal cleaning and degreasing, and wood manufacturing. Solvents also can be found in a variety of household consumer products including drain, oven, and pipe cleaners, shoe polish, household degreasers, typewriter correction fluid, deodorizers, leather dyes, photographic supplies, tar remover, waxes, and pesticides. According to the [EPA Toxic Release Inventory] TRI, during 1998–2001, total on- and off-site releases of methylene chloride, PCE [perchloroethene], TCE [trichloroethene], and TCA [1,1,1-trichloroethane] averaged about 33 million pounds, 4 million pounds, 11 million pounds, and 0.5 million pounds, respectively. PCE is still the solvent of choice for 85 to 90 percent of the approximately 30,000 dry cleaners and launderers in the United States.

Solvents have been associated with both acute and chronic human-health problems. Some are suspected human carcinogens, and USEPA has set Maximum Contaminant Levels (MCLs) for solvents in drinking water at very low concentrations. Many of the solvents have water solubility that are high relative to their MCLs. This means that even small spills of some solvents can result in substantial ground-water contamination problems with respect to human health. From USGS Occurrence and Implications of Selected Chlorinated Solvents in Ground Water and Source Water in the United States and in Drinking Water in 12 Northeast and Mid-Atlantic States, 1993–2002.

They become a problem when they leak from tanks, pipelines, and land fills, when they are spilled, and when they are disposed of improperly. They are the most commonly found volatile carbon-based compounds found in groundwater. They are strongly correlated with urban areas with high population densities and with groundwater having high oxygen concentrations. Perchloroethene was found most often. It was detected in 10% of the samples at levels exceeding 0.02 microgram per liter, and in 4% of the samples at levels exceeding 0.2 micrograms per liter. (Moran, 2006).

Table 16.18:



Percent of water samples with chlorinated solvent levels that exceeded EPA Maximum Contaminant Levels. From Moran (2006).

G. Pesticides

Pesticides are any substance or mixture intended to prevent, kill, or repel any pest, including insects, weeds, mice, fungi, or bacteria. Thus, household chemicals to disinfect surfaces or to remove mildew are legally classified as pesticides.

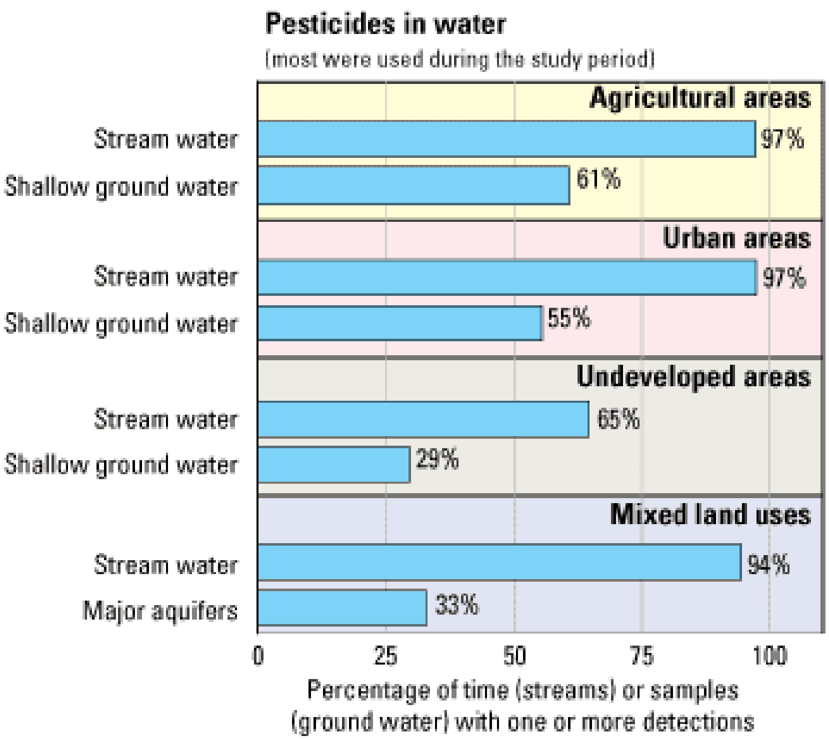
Total pesticide use in the United States has remained relatively constant at about 1 billion pounds per year [excluding chlorine/ hypochlorates (2.6 billion pounds per year), wood preservatives (1 billion pounds per year), and special biocides (0.3 billion pounds per year)] , after growing steadily through the mid-1970s because of increased use of herbicides. Agriculture now accounts for 70 to 80 percent of total pesticide use. Most agricultural pesticides are herbicides, which account for about 60 percent of the agricultural use. Insecticides generally are applied more selectively and at lower rates than herbicides. Major changes in insecticide use have occurred over the years in response to environmental concerns, which have resulted in various restrictions on the use of organochlorine insecticides, such as DDT. Specifically, as the use of these persistent pesticides declined, the use of other, less persistent insecticides increased. From USGS Sources of nutrients and pesticides

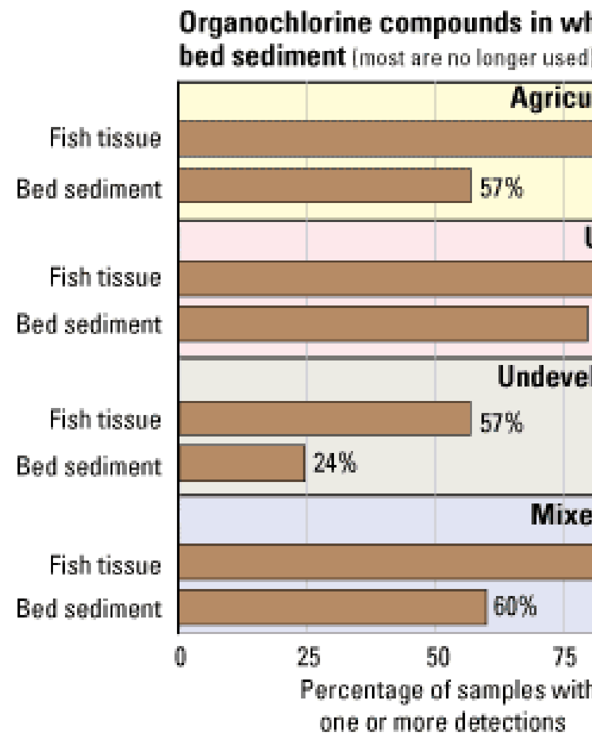
Glyphosate is by far the most commonly used herbicide, but it is of little concern because glyphosate doesn't readily leach into water systems. Instead, it latches tightly to soil particles and degrades within weeks into harmless byproducts. By contrast, herbicides such as atrazine have been widely implicated in contaminating groundwater. (Service, 2007).

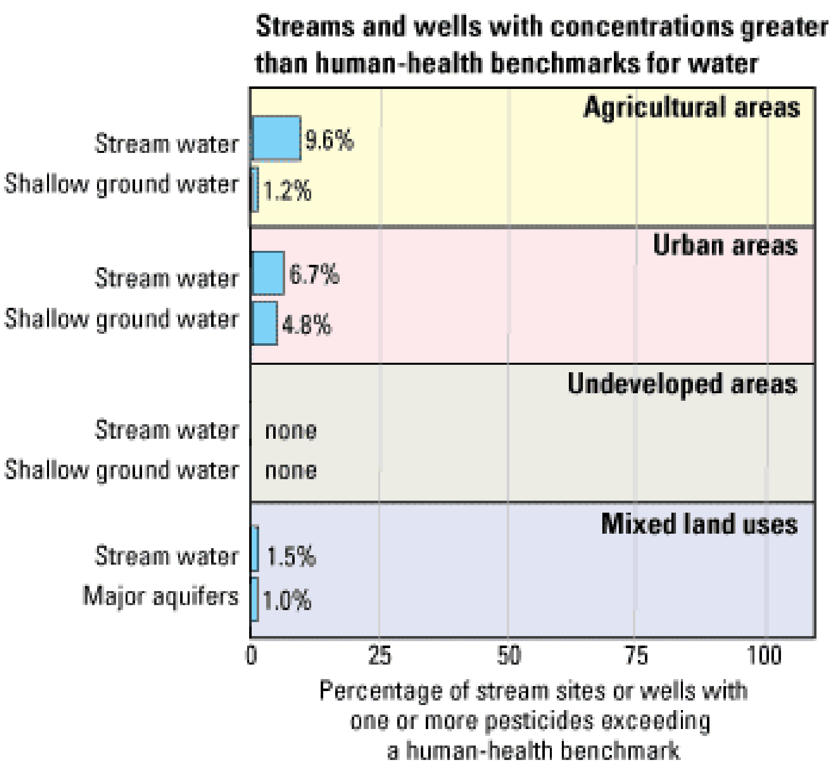
The US Geological Survey conducted a national survey of Pesticides in the Nation's Streams and Ground Water, 1992–2001, and issued a summary in 2006.

Among the major findings are that pesticides are frequently present in streams and ground water, are seldom at concentrations likely to affect humans, but occur in many streams at concentrations that may have effects on aquatic life or fish-eating wildlife. Human-health benchmarks were seldom exceeded in ground water. One or more pesticides exceeded a benchmark in about 1 percent of the 2,356 domestic and 364 public-supply wells that were sampled. The greatest proportion of wells with a pesticide concentration greater than a benchmark was for those tapping shallow ground water beneath urban areas (4.8 percent). (Pesticides in the Nation's Streams and Ground Water, 1992–2001—A Summary).

Table 16.19:





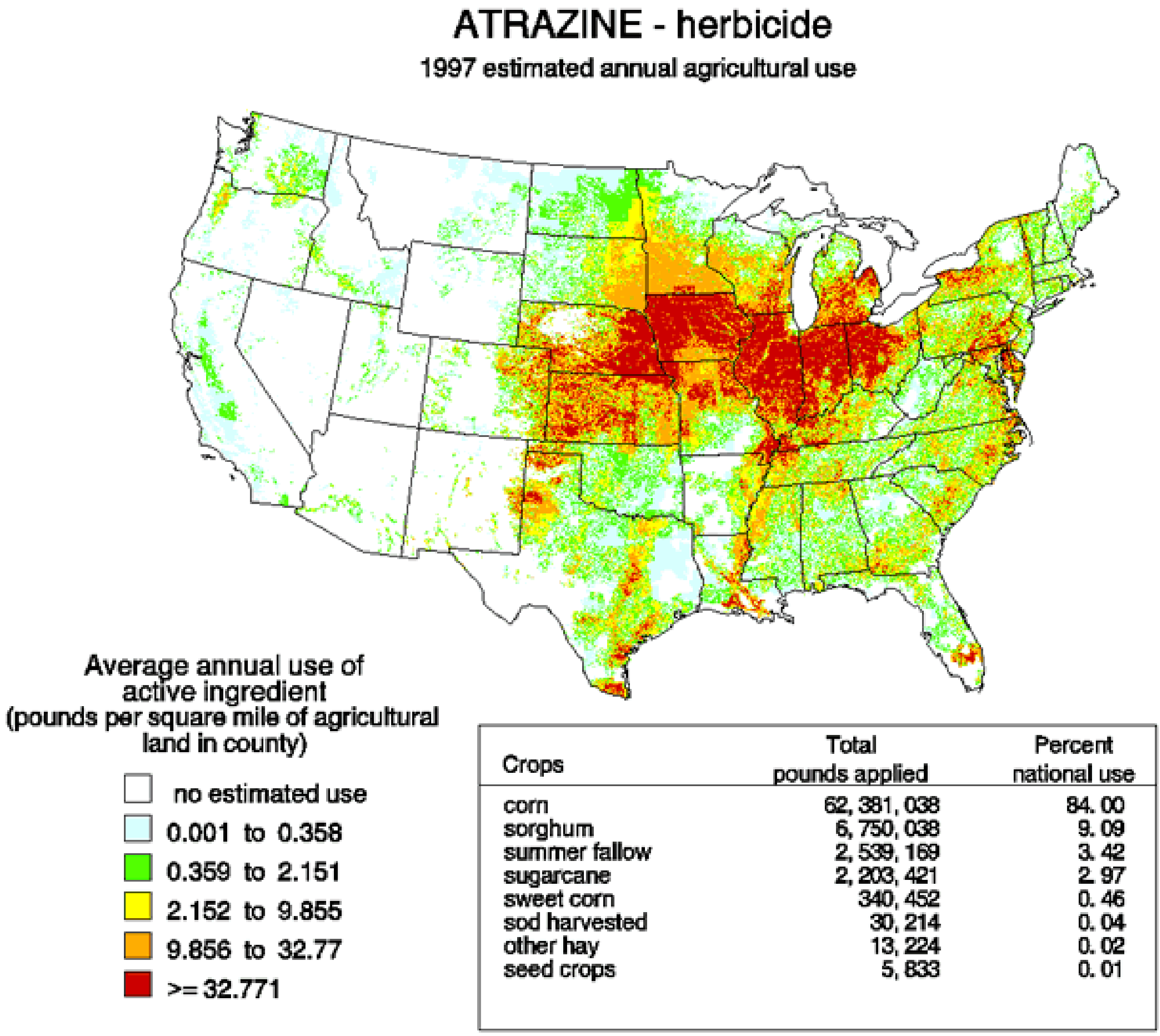


From US Geological Survey

Pesticides in the Nation's Streams and Ground Water, 1992–2001—A Summary.

Atrazine is the pesticide most commonly found in rural water, being found in 20% of shallow groundwater sites surveyed by the US Geological Service as reported in Barbash (1999). Prometon is the most common pesticide in urban water, being found in 5% of shallow groundwater sites surveyed.

Table 16.20:



Atrizine use in US in 1997. The map may be somewhat misleading because farmers now use mostly glyphosate to control weeds in corn. From US Geological Service Pesticide Use Maps.

H. Metals (Natural and Anthropogenic)

Metals leach from landfills, old mines, and industrial sites. Batteries, electronic equipment, metal plating operations, metal smelters, all contribute. The US Geological Survey web page on Groundwater Quality lists the major natural and human-produced sources.

Small amount of metals are essential to life. Higher concentrations can be toxic. In addition, the toxicity of the metal also depends on its chemical compound. For example, metallic mercury is not toxic. But methyl mercury $(CH_3)_2Hg$ is a highly toxic neurotoxin. It is produced by sulfate-reducing bacteria living in environments with low oxygen concentration. Chromium III is essential for humans, chromium VI is very toxic. Chromium VI compounds are readily soluble in water.

I. Nutrients

Nutrients are chemical elements that are essential to plant and animal nutrition. Nutrients include ammonia, urea, ammonium nitrate, and ammonium sulfate, potassium chloride, and diammonium phosphate. They enter aquifers from rain and irrigation water leaching the compounds from the soil after fertilizer was applied by households and farmers.

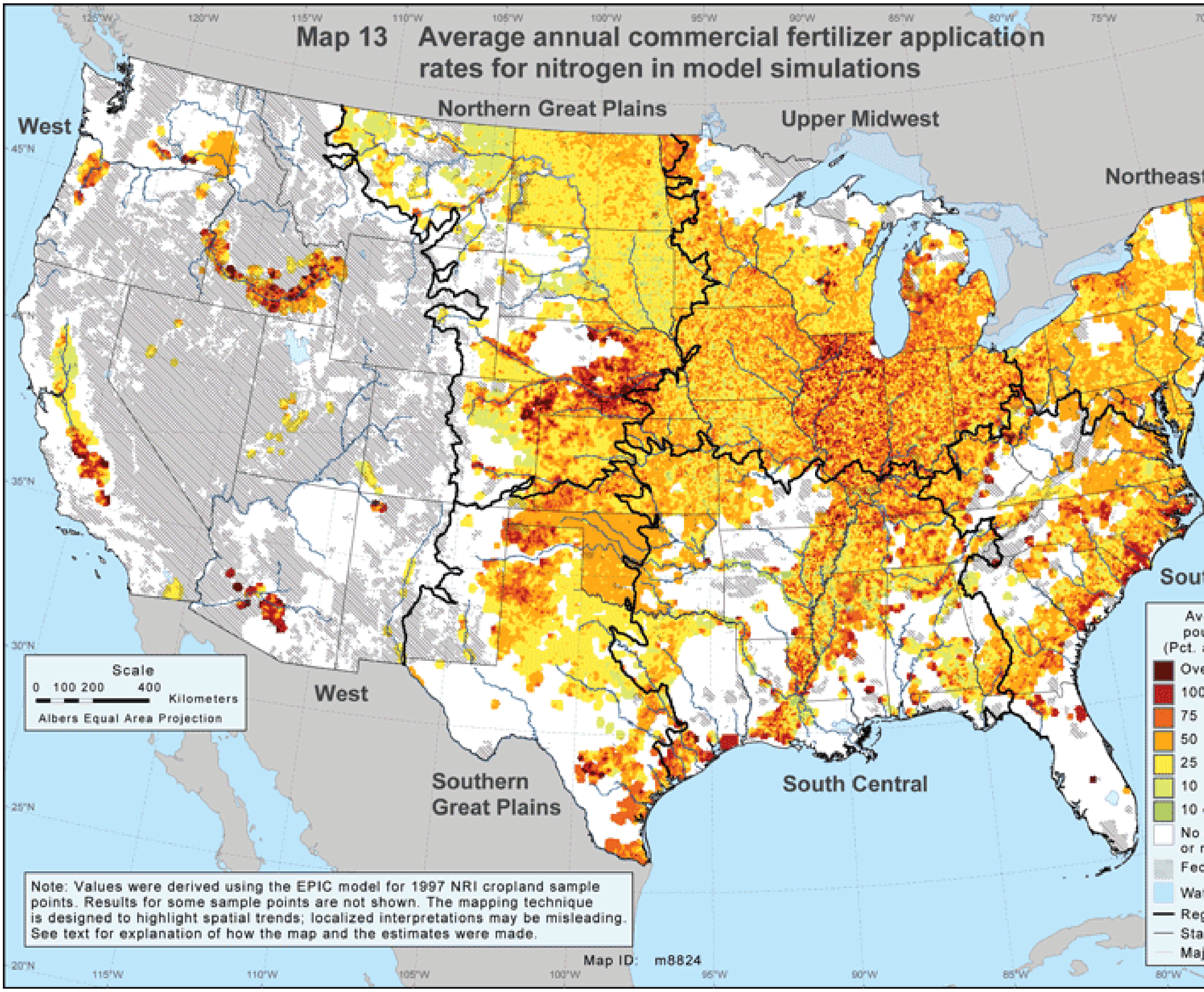
About 11.5 million metric tons per year (Mt/yr) of nitrogen in all forms is used in fertilizers in the United States. Ammonia represents about 32 percent of the total fertilizer nitrogen used; urea and urea-ammonium nitrate solutions together represent 37 percent; ammonium nitrate, 5 percent; and ammonium sulfate, 2 percent.

Phosphate rock, when used in an untreated form, is not very soluble and provides little available phosphorus to plants, except in some moist acidic soils. Treating phosphate rock with sulfuric acid makes phosphoric acid, the basic material for producing most phosphatic fertilizers. Phosphatic fertilizers include diammonium phosphate (DAP) and monoammonium phosphate (MAP), which are produced by reacting phosphoric acid with ammonia, and triple superphosphate, produced by treating phosphate rock with phosphoric acid. More than 90 percent of the phosphate rock mined in the United States is used to produce about 12 Mt/yr of phosphoric acid. Domestic consumption of phosphate in fertilizers has averaged 4.5 Mt/yr since 1994.

Potassium is found in potash, a term that includes various mined and manufactured salts; all contain potassium in a water-soluble form. Potash is produced at underground mines, from solution-mining operations, and through the evaporation of lake and subsurface brines. Minerals mined for potash include potassium chloride [KCl or muriate of potash (MOP)], potassium-magnesium sulfate [K2SO4 · MgSO4 or sulfate of potash magnesia (SOPM)], or mixed sodium-potassium nitrate (NaNO3+KNO3 or Chilean saltpeter). Manufactured compounds are potassium sulfate [K2SO4 or sulfate of potash (SOP)] and potassium nitrate (KNO3 or saltpeter). The United States consumes about 11 Mt/yr tons of potash of all types and grades. From U.S. Geological Survey Fact Sheet 155-99 on Fertilizers – Sustaining Global Food Supplies.

Nitrate concentrations in groundwater is highest in areas of well-drained soils and intensive cultivation of row crops, such as corn, cotton, or vegetables. Low concentrations are found in areas of poorly drained soils and where pasture or woodland is intermixed with cropland in agricultural areas. From Mueller and Helsel (1996).

Table 16.21:



Average annual commercial fertilizer application rates for nitrogen in US. From Natural Resources Conservation Service, Model Simulation of Soil Loss, Nutrient Loss and Soil Organic Carbon Associated with Crop Production Appendix.

16.8 Groundwater Remediation

Contaminants must often be removed from groundwater before it reaches wells used by agriculture and municipal water systems. The removal of containment of pollutants is called remediation. In this chapter we will examine the various ways pollutants are evaluated, traced, and removed from groundwater.

When Is It Needed?

Remediation is required when concentrations of contaminants exceed or are expected to exceed predetermined levels for the type of resource that is impacted. For example, lead levels in drinking water should not exceed the EPA action level of 0.015 mg/L. What caused the high levels of lead? How can the lead be removed from the aquifer?

Under Subtitle I of the 1984 Resource Conservation and Recovery Act (RCRA), Congress directed the Environmental Protection Agency to publish regulations that would require owners and operators of new tanks and tanks already in the ground to prevent, detect, and clean up releases. Title XV, Subtitle B of the Energy Policy Act of 2005 (entitled the Underground Storage Tank Compliance Act of 2005) contains amendments to Subtitle I of the Resource Conservation and Recovery Act. This new law significantly affects federal and state underground storage tank programs, will require major changes to the programs, and is aimed at reducing underground storage tank releases to our environment.

> EPA's federal underground storage tank (UST) regulations require that contaminated UST sites must be cleaned up to restore and protect groundwater resources and create a safe environment for those who live or work around these sites. Petroleum releases can contain contaminants like MTBE and other contaminants of concern that can make water unsafe or unpleasant to drink. Releases can also result in fire and explosion hazards, as well as produce long-term health effects. From Cleaning Up Underground Storage Tank System Releases.

Under Subtitle D of RCRA, Congress directed the EPA to issue regulation for control and clean up landfill releases. Other federal rules and regulations cover remediation of superfund sites.

Six Steps to Treating a Contaminated Aquifer

Suppose a gas-station owner discovers that a gasoline tank has been slowly leaking for many years. Where has the gasoline gone? Will it cause a problem? How can the leaked gasoline be cleaned up, especially if it has reached an aquifer? The owner now has a groundwater-remediation problem.

Or suppose a contractor building a new office tower notices gasoline fumes coming from below the foundation. What is the source? Can the aquifer below the site be cleaned up so fumes will not leak into the building after it is built? This too is a groundwater-remediation problem.

Online Information Remediating groundwater contamination is not easy or cheap. Several organizations have published useful web pages on remediation:

1. The Canadian government Contaminated Sites Management Working Group publishes a Site Remediation Technologies Reference Manual with much more detailed information.
2. The US Environmental Protection Agency also provides information on remediation technologies.
3. The US Geological Survey, through their Toxic Substances Hydrology Program provides useful information.

Remediation Steps

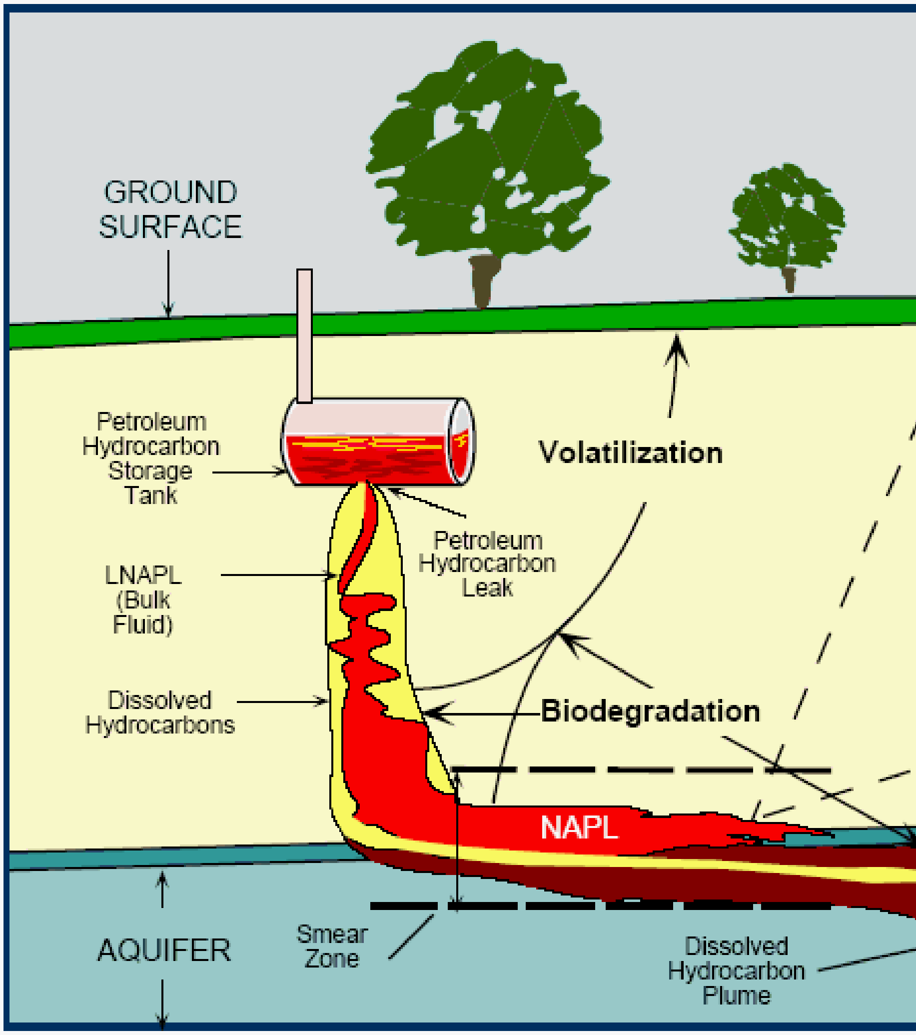
1. Discovery and Source Determination

What do we know about the source and the contaminant?

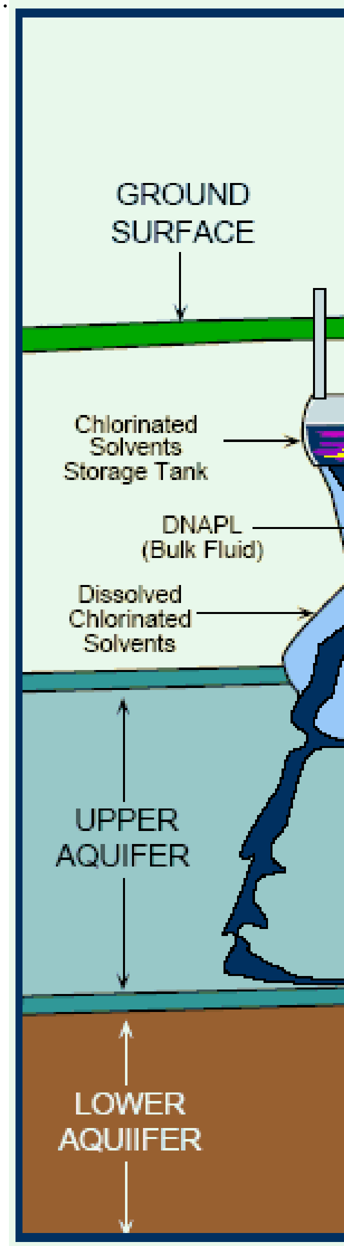
1. What contaminant(s) are leaking into the aquifer?
   (a) Many different types of chemical compounds are released from landfills, industrial activity, end even and gasoline tanks. You may thing gasoline is relatively simple, but in addition to many volatile organic (carbon-based) compounds, gasoline also has toxic anti-knock compounds such as tetraethyl lead (up until 1986) and methyl tertiary-butyl ether (MTBE).
   (b) How long has the source leaked contaminants?
2. What is the spatial extent of the source?
   (a) Is it contained to a relatively small area such as a leaking gasoline tank?
   (b) Is it spread over many acres, such as a leaking landfill?
   (c) Is it spread over many square kilometers such as a military installation or large mine?
3. What are the physical properties of the contaminant?
   (a) Density (is it heavier or lighter than water)?
   (b) Viscosity?
4. What are the chemical properties of the contaminant?
   (a) Does it dissolve in water?
   (b) How does it react with oxygen, rock, or sediments in the aquifer?
5. What is their concentration at various locations of an extended source? Large industrial sites may have multiple leaking underground tanks and disposal areas scattered over many square kilometers.
6. Toxicology.
   (a) What is the effect of the toxic contaminant on plants, animals, humans or an ecosystem?
   (b) Is the toxiticity high enough to kill people or wildlife?

Density effects how contaminants move through an aquifer. Light Non-Aqueous Phase Liquids

LNAPL such as gasoline float on water.



Dense Non-Aqueous Phase Liquids DNAPL such as dry-cleaning solvents sink in water.



2. Removal of the Source

Once a source has been found, the most important first step toward remediation is to remove the source if feasible. Removal often involves excavation of leaky tanks and contaminated soil. Once the source is removed, the next step is to clean up contaminated water still in the ground.

Table 16.22:

Employees of Cortland Pump and Equipment Company and Sherman Vincent Associates General Contractors remove the concrete above the gasoline storage tanks at a gas station in Jacksonville, FL.

3. Site Characterization

What do we know about the geologic and hydraulic properties of the aquifer into which the contaminants leaked?

1. What is the extent of the aquifer? How deep? How wide? Location of aquatards?
2. What are the physical properties of the aquifer?
   (a) Pore size?
   (b) Sediment or rock type?
   (c) Hydraulic diffusivity?
   (d) How fast does the water flow through the aquifer?
3. What are the chemical properties of the rock and sediment within the aquifer?
   (a) How pure is the aquifer upstream of the source of contamination? This helps separate what is introduced by the source from what is otherwise occuring in the aquifer.
   (b) What gases are disolved in the aquifer. For example, how much oxygen is in the water?

4. Impact Evaluation

1. What has happened to the the contaminant within the aquifer?
   (a) How far has has the contaminant spread?
   (b) Has the chemical composition changed due to natural remediation?
   (c) Answers to these questions comes mostly from a multiple well drilled into the aquifer.

2. The monitoring wells give the extent of the plume of contaminants and the rate at which they move through the aquifer. Wells are expensive to drill and operate, so much care must go into selecting sites for wells. And, because few wells can be drilled, our ability to visualize the subsurface is less than perfect. We are ”looking” through pinholes.

5. Modeling

It is not possible to completely monitor conditions within the plume and to predict future changes. Models are used to help interpolate conditions between monitoring wells, and to predict possible changes in the future. Additional wells and monitoring will be needed to test the predictions.

6. Remediation

This involves removing or containing the plume of contaminants within an aquifer. Many methods have been devised and used to treat the many types of contaminants in the many types of aquifers. Eight of the more common remediation methods are discussed below.

Remediation Considerations:

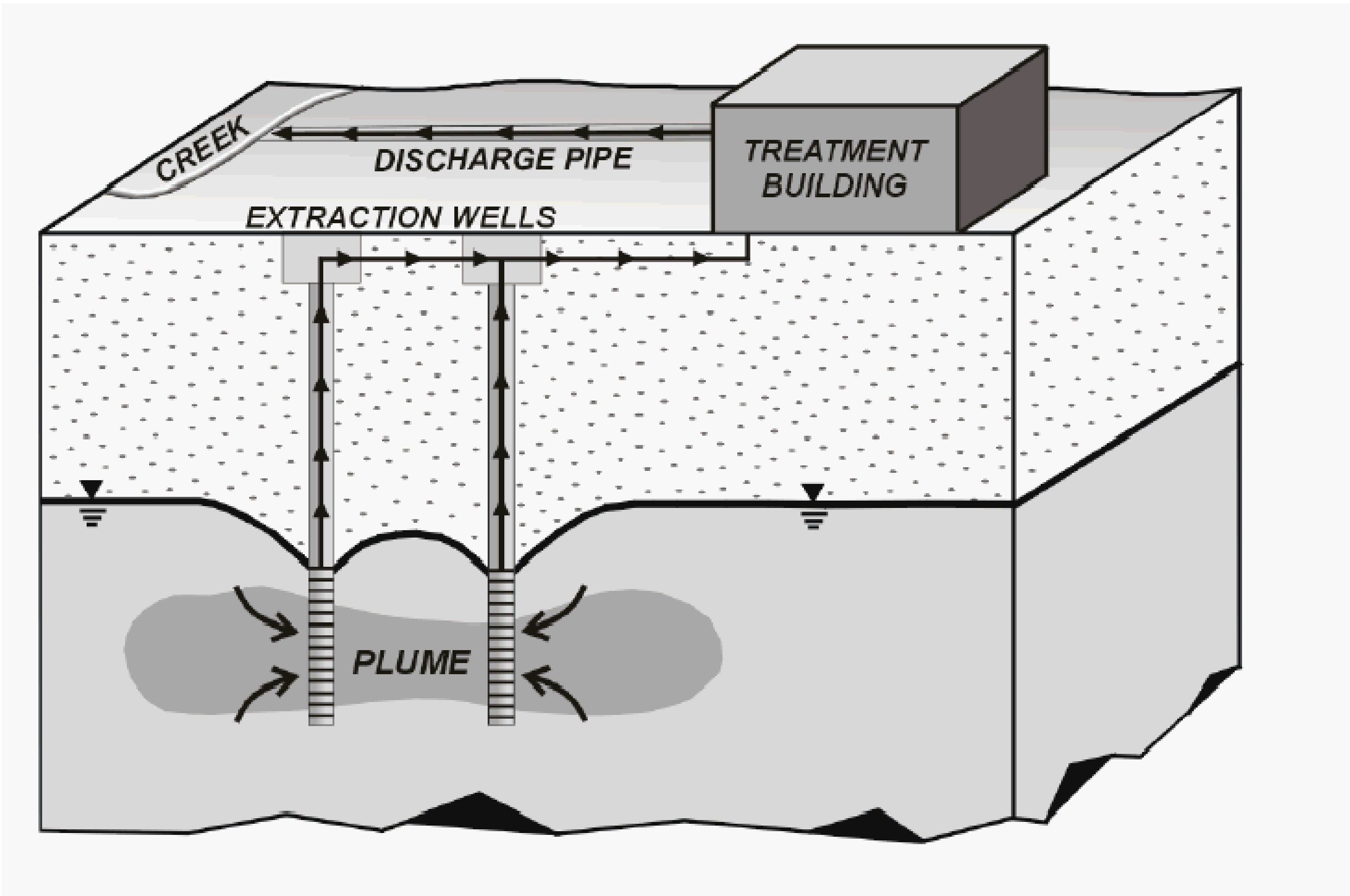
The method chosen for remediation depends on the several factors:

1. Hydrogeologic setting
2. Contaminant characteristics
3. Physical properties (sink or float)
4. Chemical properties (solubility, sorption)
5. Subsurface access, land use
6. Toxicity-risk
7. Cost. All are expensive, and some are much more expensive than others.

Many remediation methods are used. The more common are:

1. **Pump-and-treat** This involves removing contaminated groundwater from strategically placed wells, treating the extracted water after it is on the surface to remove the contaminates using mechanical, chemical, or biological methods, and discharging the treated water to the subsurface, surface, or municipal sewer system.

Table 16.23:



From Environment Protection Agency. The method has several limitations.

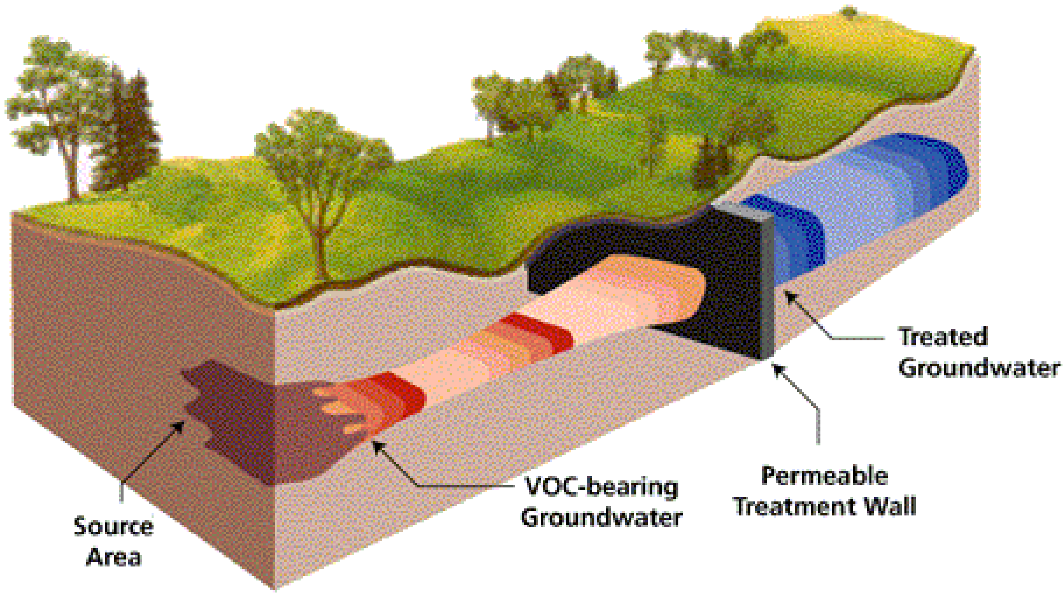
2. **Hydraulic Containment** Pumping water from wells can be done in such a way that it changes the flow of water through an aquifer in ways to keep contaminants away from wells used for cities or farms. The technique works if the flow through the aquifer is relatively simple, so the plume of contaminated water does not divide into different paths. It is often used together with pump and treat, and it has the same limitations.
3. **Air Sparging/Soil Vapor Extraction** The limitations include:
   (a) difficulty flushing in low permeability zones,
   (b) difficulty operating below 9m (30ft),
   (c) difficulty extracting multicomponent phases.
4. **In-situ Oxidation** This method injects an oxidant such as hydrogen peroxide (H2O2) into the contaminated aquifer. The contaminant is oxidized, primarily producing carbon dioxide and water.

An example of injection of chemicals that remove contaminants from an aquifer. Here a permeable treatment zone is created by reducing the ferric iron in the aquifer sediments to ferrous iron by injecting a reducing reagent and appropriate buffers such as sodium dithionite and potassium carbonate. Click on the image for a zoom. From Field Hydrology and Chemistry

Group of the Pacific Northwest National Laboratory of the US Department of Energy.

Permeable Reactive Barriers This methods uses a trench backfilled with reactive material such as iron filings, activated carbon, or peat, which absorb and transform the contaminant as water from the aquifer passes through the barrier. This works only for relatively shallow aquifers.

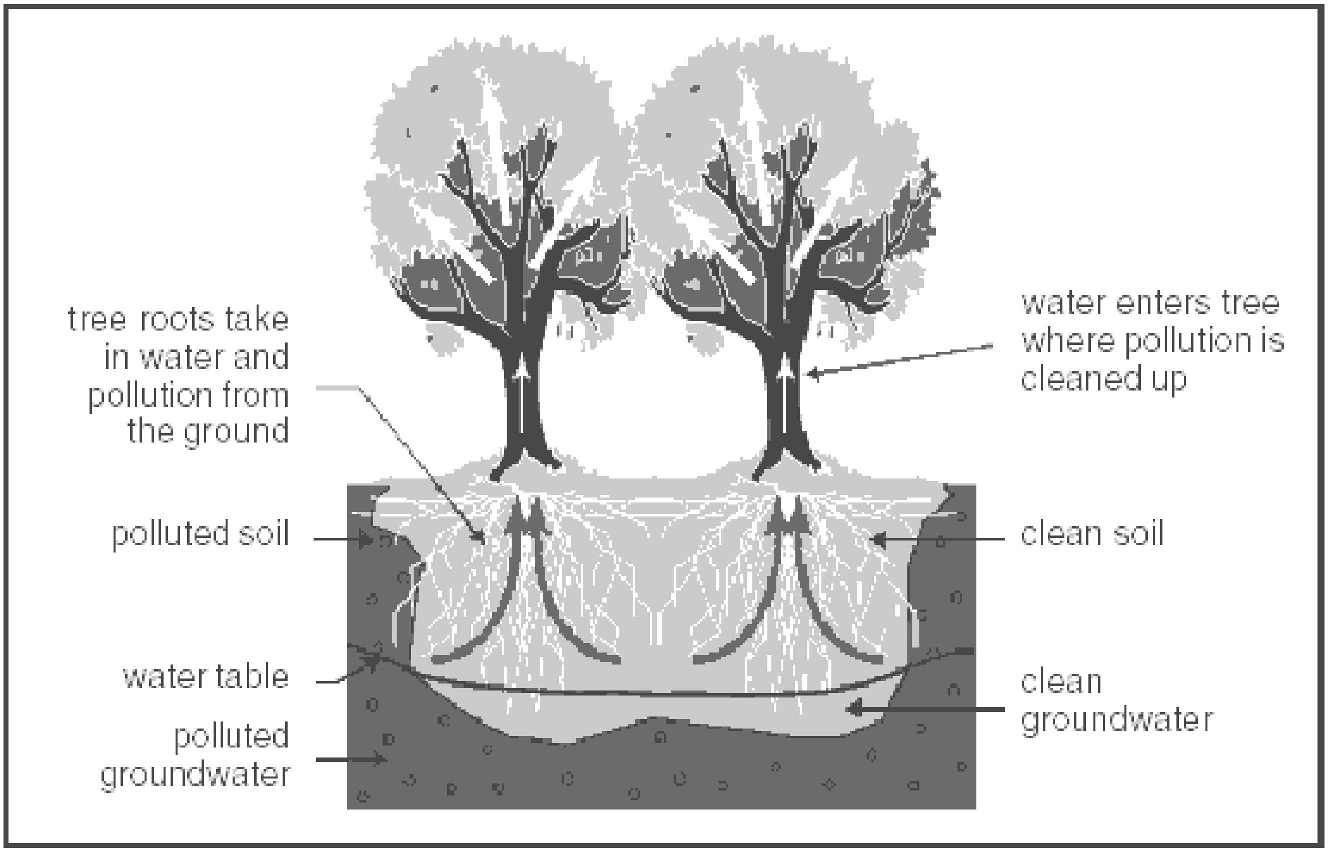
Left: A Dewind Trencher



installs a permeable treatment barrier in a trench. Click on the image for a zoom. From EPA Research Highlights. Right: The barrier absorbs contaminants (in this image VOC is Volatile Organic Carbon) leaving treated water to flow downstream in the aquifer. Click on the image to download a 1.3 MByte animation. FromDewind One Pass Trenching.

Phytoremediation Some plants accumulate heavy metals and metal like elements, such as arsenic, lead, uranium, selenium, cadmium, and other toxins such as nutrients, hydrocarbons, and chlorinated hydrocarbons. Chinese Ladder fern Pteris vittata, also known as the brake fern, is a highly efficient accumulator of arsenic. Genetically altered cottonwood trees suck mercury from the contaminated soil in Danbury Connecticut. And, transgenic Indian mustard plants to soak up dangerously high selenium deposits in California. The remediation consists of growing such plants so their roots tap the groundwater. Then, the plants are harvested and disposed. The method is limited to remediation of groundwater that is close enough to the surface that it can be reached by plant roots.

Table 16.28:

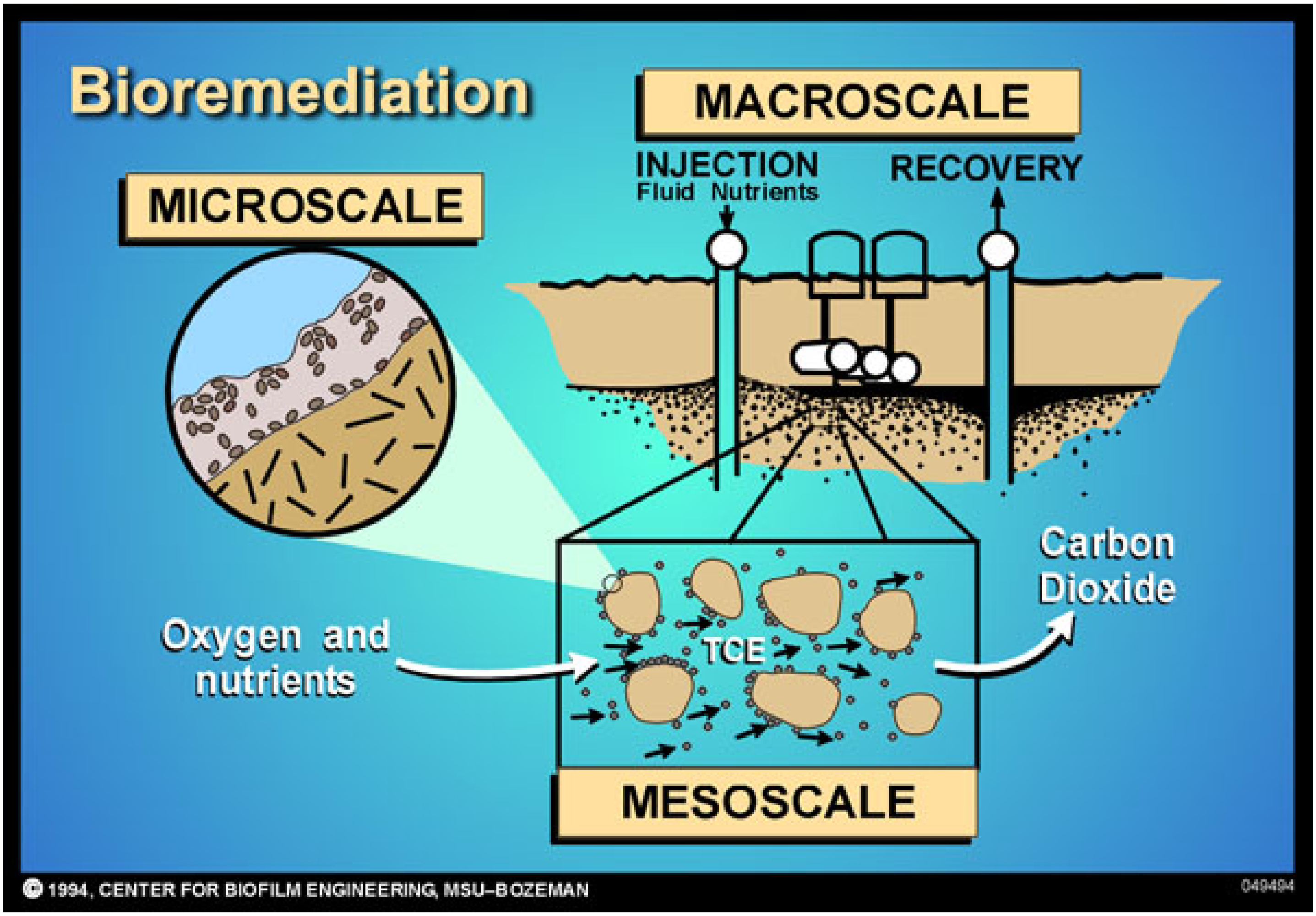


From Environmental Protection Agency: A Citizen's Guide to Phytoremediation. A typical plant may accumulate about 100 parts per million (ppm) zinc and 1 ppm cadmium. Thlaspi caerulescens (alpine pennycress, a small, weedy member of the broccoli and cabbage family) can accumulate up to 30,000 ppm zinc and 1,500 ppm cadmium in its shoots, while exhibiting few or no toxicity symptoms. A normal plant can be poisoned with as little as 1,000 ppm of zinc or 20 to 50 ppm of cadmium in its shoots. From US Department of Agriculture Phytoremediation: Using Plants To Clean Up Soils

Natural Attenuation Sometimes natural processes remove contaminants with no human intervention. The removal may involve dilution, radioactive decay, sorption (attachment of compounds to geologic materials by physical or chemical attraction), volatization, or natural chemical reactions that stabilize, destroy, or transform contaminants.

Intrinsic and Enhanced Bioremediation Biodegradation is the breakdown of carbon-based contaminants by microbial organisms into smaller compounds. The microbial organisms transform the contaminants through metabolic or enzymatic processes. Biodegradation processes vary greatly, but frequently the final product of the degradation is carbon dioxide or methane. Biodegradation is a key processes in the natural attenuation of contaminants at hazardous waste sites. USGS Toxic Substances Hydrology Program. Bacteria and archaea can metabolize hydrocarbons and other contaminants, converting them to less toxic products. Some live deep underground, some live in the absence of oxygen. Specific organisms are injected into the groundwater, and in some cases, special nutrient are injected with the microbes. The method is especially useful for remediation of hydrocarbons in groundwater. Natural bioremediation occurs when naturally occurring bacteria living in the aquifer degrade toxic contaminants into less toxic compounds. Natural bioremediation is most effective in aquifers where bacteria are plentiful, and where contaminant levels are low. Enhanced bioremediation involves stimulating natural bacteria by injecting nutrients and/or carbon compounds needed by the bacteria into the aquifer.

Table 16.29:



Nutrients and carbon compounds are injected into an aquifer (macroscale sub-image) to stimulate naturally occurring bacteria living in biofilms on sediment particles (microscale sub-image). The bacteria break down contaminants such as trichloroethylene TCE into non-toxic compounds such as carbon dioxide (mesoscale sub-image). From Center for Biofilm Engineering at Montana State University-Bozeman.

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking water, medicine, agriculture, and industrial processes.

People living in developed countries suffer from few waterborne diseases and illness, because they have extensive water treatment systems to collect, treat, and redeliver clean water to their people. Many undeveloped nations have few or no water treatment facilities.

Water treatment is any process used to remove unwanted contaminants from water (Figure 21.22). Water treatment processes are designed to reduce harmful substances such as suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria. Ideally, water treatment produces both liquids and solid materials that are not harmful the natural environment.

Water can contain hundreds of contaminants. Not all treatment processes are able to remove all of these particles and not all treated water is pure enough to qualify as safe drinking water. **Sewage treatment** is any process that removes contaminants from sewage or wastewater. **Water purification** is any process used to produce drinking water for humans by removing contaminants from untreated water. Purification processes remove bacteria, algae, viruses, and fungi, unpleasant elements such as iron and sulphur, and man-made chemical pollutants.

The choice of treatment method used depends on the kind of wastewater being treated. Most wastewater is treated using a series of steps, increasingly purifying the water at each step. Treatment usually starts with separating solids from liquids. Water may then be filtered or treated with chlorine. With each subsequent step, the water has fewer contaminants and the effluent is increasingly pure.

16.9 Reducing Water Pollution

How can people reduce water pollution? And who is responsible for doing it?

People have two ways to reduce any kind of pollution: We can prevent people from polluting water. And, we can use science to clean contaminants from water that is already polluted.

Governments can:

- Pass laws to control pollution emissions from different sources, such as factories and agriculture.
- Pass laws that require polluters to clean up water they pollute.
- Provide money to build and run water treatment facilities (and fund research to improve water quality technology).
- Educate the public, teach them how to prevent and clean up water pollution.
- Enforce laws.

The United Nations and other international groups have established organizations to improve global water quality standards. Some international organizations provide developing nations with the technology and education to collect, treat, and distribute water. Another priority is educating the people in these countries about how they can help improve the quality of the water they use.

In the United States, legislators passed the Clean Water Act which gives the Environmental Protection Agency the authority to sets standards for water quality for industry, agriculture and domestic uses.

One of the toughest problems is enforcement, catching anyone who is not following water regulations. Scientists are working to create methods to accurately track the source of water pollutants. Monitoring (tracking) methods allow the government to identify, catch and punish violators.

Who is responsible for reducing water pollution? Everyone who pollutes water is responsible for helping to clean it up. This includes individuals, communities, industries, and farmers.

Just a few of the things you can do to protect water quality include:

- Find approved recycling or disposal facilities for motor oil and household chemicals so these substances do not end up in the water.
- Use lawn, garden, and farm chemicals sparingly and wisely.
- Repair automobile or boat engine leaks immediately.
- Keep litter, pet waste, leaves, and grass clippings out of gutters and storm drains.

16.10 Controlling Ocean Pollution

Controlling seawater pollution and fresh water pollution are similar, but not exactly the same. We can try to prevent polluters from further spoiling the ocean and we can require polluters to clean up any pollution they cause. Government and international agencies can pass laws, provide funding, and enforce laws to prevent and clean up ocean pollution (Figure 21.24).

Several national and international agencies monitor and control ocean pollution. The agencies include the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency, the Department of Agriculture as well as other federal and state agencies.

When runoff pollution does cause problems, NOAA scientists help track down the exact causes and find solutions. This organization is also one of many organizations trying to educate the public on ways to prevent ocean pollution.

Table 16.30:

16.11 Conserving Water

As human population growth continues, water conservation will become increasingly important globally (Figure 21.25). Yet, the methods to conserve water are likely to differ between developing nations and developed countries.

For example, some people in undeveloped countries use so little water, that they may not gain much water by reducing their personal use. Meanwhile, large quantities of water can be conserved in the United States by finding ways to stop over-consumption of water.

At Earth Summit 2002 many governments approved a Plan of Action to address the scarcity of water and safe drinking water in developing countries. One goal of this plan is to cut in half, the number of people without access to safe drinking water by 2015.

Developed countries have many options to reduce water consumption. A farmer can cut water consumption drastically by using more efficient irrigation methods. People also have many opportunities to reduce our personal and household water demand with such measures as low flow shower heads, toilets that use less water, and drip irrigation to water lawns.

During prolonged droughts and other water shortages, some communities ration water use and prohibit such water intensive uses as watering lawns during the day and hosing down sidewalks. Often legislation is needed to provide incentives for individuals to reduce their water consumption.

Conserving Water and Other Natural Resources

Can you imagine what the expression "**virtual water**" could mean? It is an important concept in the conservation of water resources.

Virtual water is the water used in the production of a good or service. Although it is no longer contained in the product, its use is a part of the cost of production, and as such should be factored into the product's value. Here are some estimates of virtual water ''contained'' in various products, from the United Nations Education, Scientific, and Cultural Organization (UNESCO) Institute for Water Education:

- 1 kg wheat:1,300 liters
- 1 kg beef:15,000 liters
- 1 pair of jeans: 10,850 liters

The more water we use, the more likely we are to draw down wells and rivers beyond the hydrologic cycle's power to recharge them. The more water we use, the more we are likely to pollute the 1% of Earth's waters which are fresh (as well as the oceans). Protecting soils and lands (especially wetlands and watersheds) is a critical part of protecting water resources, because the hydrologic cycle integrates terrestrial and aquatic ecosystems.

Thus, as for all conservation (wise use) or **sustainable use** (meeting needs of the present without impairing those of future generations), the first step is to reduce our use of water. This and other strategies to protect our water resources are summarized below. Don't forget the list of what you can do as an individual, at the end of the lesson on biodiversity!

1. Reduce the use of water, and the abuse of soil, land, and wetlands.

   - Landscape with native, drought-resistant vegetation.
   - Use low-flow toilets, faucets, and showerheads. Check out possible local government subsidies for installing these water saving mechanisms.
   - Purchase foods from water-efficient crops which do not require irrigation.

2. Reuse water where appropriate.

   - Gray water, which has been used for laundry or washing, can be used to water gardens or flush toilets.
   - On a municipal level, sewage water can be used for fountains, watering public parks or golf courses, fire fighting, and irrigating crops that will be boiled or peeled before consumption.

3. Catch runoff, which will also slow non-point source pollution and erosion.

   - Place rainbarrels adjacent to buildings.
   - Recharge pits which will re-fill aquifers.

4. Support legislation that reduces pollution.

   - For example in the U.S., the 1977 Clean Water Act, through the EPA, regulates industrial discharge of contaminants and sets standards for water quality.

5. Work locally, nationally and internationally to make clean fresh water available.

   - The United Nations Depart of Economic and Social Affairs has initiated a second Decade for Water for Life, 2005-2015 to increase awareness of water shortages and work toward sustainable use of freshwater resources.
   - The World Water Council unites 300 member organizations from 60 countries to work to ''build political commitment and trigger action on critical water issues at all levels... to facilitate the efficient management and use of water …on an environmentally sustainable basis.''

16.12 End of Chapter Review & Resources

Chapter Summary

Water is a renewable resource, but it is not unlimited. Humans are limited to less than one percent of the water on Earth. Also, water is not evenly distributed across the globe. Water is so valuable that countries have fought each other over water rights throughout history. Water shortages and water pollution have become so serious across the world, that some organizations call our water status a ”water crisis”. The crisis is blamed on overpopulation, overuse of water, pollution, and global warming. Undeveloped countries are rarely able to afford water treatment and purification facilities, unless other countries and international organizations help. Water mining and overuse have reduced the available water in many parts of the world. As you learned about in the chapter on desertification, dried and dying sea beds cause environmental problems through dust storms, drought and water limitations. Water pollution can occur from many different domains, including: landfills, hazardous waste, agriculture, mining, storage tanks, septic systems, injection wells, pesticides, metals, and nutrients. The steps in remediation are, 1) discover the source of contamination, 2) stop or remove the source, 3) site characterization, 4) impact evaluation, 5) modeling, 6) remediation. There are several ways to conduct the remediation, such as 1) pump and test, 2) hydraulic containment, 3) air sparging, 4) soil vapor extraction, 5) in-situ oxidation, 6) permeable reactive barriers, 7) phyto remediation, 8) natural attenuation, 9) bioremediation. Many technologies are available to conserve water as well as to prevent and treat water pollution. Yet, most undeveloped countries cannot afford the technology they need to collect, treat and distribute water to their people. Developing countries may be able to afford water treatment systems, but people still need incentives to use conservation steps.Liquid fresh water, the primary water resource for human use, comprises less than 1% of all water on Earth; most of this is groundwater. As industry, agriculture, development, and a growing world population use more water, fresh water supplies are shrinking due to over-drafting of groundwater and pollution of surface and groundwater. According to the United Nations, the current Water Crisis involves 1.1 billion people without adequate water supplies and 2.6 billion people who lack adequate water for sanitation. Agricultural fertilizer runoff and waste water add excess nutrients to surface waters, leading to algal blooms and eutrophication. Dead zones in coastal areas such as the Gulf of Mexico result from agricultural runoff from large areas of land. The dead zone at the mouth of the Mississippi River was the size of New Jersey in the summer of 2007. The more water we use, the more likely we are to overdraft aquifers and pollute water supplies. Concepts similar to virtual water highlight the importance of REDUCING USE as a first principle in conservation or sustainable use. A second principle is to REUSE resources. For water conservation, this can mean re-using gray water from laundry or showers for gardens or flush toilets. Legislation can set standards for water quality and limits on pollution.

Review Questions

1. What is the purpose of water treatment and purification?
2. How can governments and international organizations help to reduce water pollution?
3. Name three things that a person could do to reduce pollution?
4. Name three ways that you could reduce your personal water use.
5. Who is responsible for controlling water pollution?
6. What can governments and international organizations do to control pollution?
7. It is usually cheaper to dump polluted water without spending money to treat and purify the water. What incentives would convince industry to control water pollution?
8. Explain what a dead zone is and where you might find one?
9. What is runoff and why is it a problem?
10. Water pollution not only harms human health and the environment. Consider how this reduces the

amount of water available to humans.

11. Ocean pollution harms some of the most productive sources of marine life. How can we change our behaviors to protect marine life?
12. Fifty percent of all infectious diseases are caused by water pollution. What can be done to reduce the number of pathogens that reach our freshwater supplies?
13. Give two reasons why water shortages are happening around the world today?
14. How do droughts affect water supplies?
15. Why does the United Nations describe the current water status today as a crisis?
16. If most of the Earth is covered with water, how can there be water shortages?

Further Reading / Supplemental Links

- Groundwater and Wetlands, an on-line web book.
- Circular 1139: Ground Water and Surface Water A Single Resource published by the the US Geological Survey.
- Circular 1186: Sustainability of Ground-Water Resources published by the the US Geological Survey
- Groundwater Pollution Primer, Virginia Tech

Vocabulary to Know

- aquifer - Regions of soil or rock that are saturated with water.
- arid - Regions without enough water for things to grow.
- dead zone - A region hundreds of kilometers wide without fish or plant life due to lack of oxygen in the water.
- drought - A long period of lower than normal rainfall for a particular region.
- ground water
- pathogen - Disease causing organisms.
- sewage treatment - Any process that removes contaminants from sewage or wastewater.
- water mining
- water purification - Any process used to produce safe drinking water by removing contaminants.

References

Groundwater and Wetlands, an on-line web book.

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Circular 1186: Sustainability of Ground-Water Resources published by the the US Geological Survey

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Chapter 17

Coastal Degradation & Issues

17.1 Introduction

Wetlands and coastal regions are extremely important to human natural resource economics, as well as the provide important ecosystem services that humans live upon. Pollution, degradation and destruction of these areas has seriously endangered some of the natural systems we rely on.

Chapter Objectives

- Understand important ecosystem services offered by wetlands and coastal areas.
- Understand the importance of coastal resources, such as fish.
- Compare different issues related to coastal protection policy and law.

17.2 Coast Pollution

At the intersection of land and water resources are **wetlands**: swamps, marshes and bogs whose soil is saturated (**Figure** 17.1). Historically, humans have viewed wetlands as wasted land; the U.S. has lost as much of 50% of its wetlands to agriculture, development, and flood control. Recently, wetland loss and the loss wetland species has taught us the importance of this ecosystem. Ecosystem services provided by wetlands include:

1. water storage and replenishment of aquifers
2. protection of coastlands from tides and storms
3. flood control
4. water purification I: slowing of water flow allows sedimentation to remove particulates
5. water purification II: denitrification of excess nutrients
6. rich habitat for wildlife
7. rich habitat for plants (30% of U.S. plant diversity)
8. recreation: hunting, fishing, ecotourism (e.g., The Everglades)

In the U.S., at least, recognition of the economic value and biodiversity of wetlands has led to restoration efforts and requirements for replacement of those lost through development. The Ramsar "Convention on Wetlands of International Importance, especially as Waterfowl Habitat," signed by 18 nations in 1971, works to conserve wetlands throughout the world for their ecological services and their economic, scientific, cultural, and recreational values. Signatories today number 157, and they meet every 3 years.

Figure 17.1: http://localhost/Wetlands%20such%20as%20this%20area%20in%20Cape%20May,%20New%20Jersey,%2

Importance of Coastal Regions

Coastal waters are important for many reasons:

1. People like to live near the coast. 38% of the world's population lives within 100 km of the coast. Small and Cohen (2004). It was estimated that in 2003, approximately 153 million people (53 percent of the nation's population) lived in the 673 U.S. coastal counties, an increase of 33 million people since 1980... Coastal counties constitute only 17 percent of the total land area of the United States

(not including Alaska), but account for 53 percent of the total population. 23 of the 25 most densely populated U.S. counties are coastal. Population Trends Along the Coastal United States: 1980-2008 (Crossett, 2004).

2. Many people like to go to the beach for recreation and relaxing. $8 to $10 billion is generated each year in the U.S. by coastal activities such as canoeing and kayaking, bird watching, swimming, sport fishing, and tourism. Coastal areas are also subject to major population influxes during peak vacation periods. Ocean City, MD, for example, had almost 4 million seasonal visitors between the Memorial Day and Labor Day holidays in 2003. Population Trends Along the Coastal United States: 1980-2008 (Crossett, 2004).
3. Coastal areas are a physical buffer protecting communities near the coast from storm surges and flooding.
4. Most of the important oceanic fisheries are on the continental shelf close to the coast.
5. Most of the oil and gas taken from the sea floor comes from the continental shelf and slope.
6. Estuaries are the nursery for many fish and shellfish, and they are home for much wildlife.
   (a) 75% of commercially harvested fish and shell fish depend on estuaries and nearby coastal waters for some part of their life cycle.
   (b) The Chesapeake Bay supports more than 3,000 migratory and resident species of wildlife.
   (c) Puget Sound supports 220 species of fish, 100 species of shore and sea birds, and 26 species of marine mammals.
   (d) Galveston Bay supports more than 162 species of fish.

   Let me say again: The Laguna Madre, and places like it throughout the world are natural fish hatcheries for our oceans. Fish come into these areas to spawn, then return to the Gulf. Grigar (1997) page 92.

Pollution Defined

The word pollution comes from the verb *pollute*, which means *to make unpure*. Thus pollution is:

> The action of polluting, or condition of being polluted; defilement; uncleanness or impurity caused by contamination (physical or moral). spec. The presence in the environment, or the introduction into it, of products of human activity which have harmful or objectionable effects. From the *Oxford English Dictionary*.

Notice that pollution is the product of human activity.

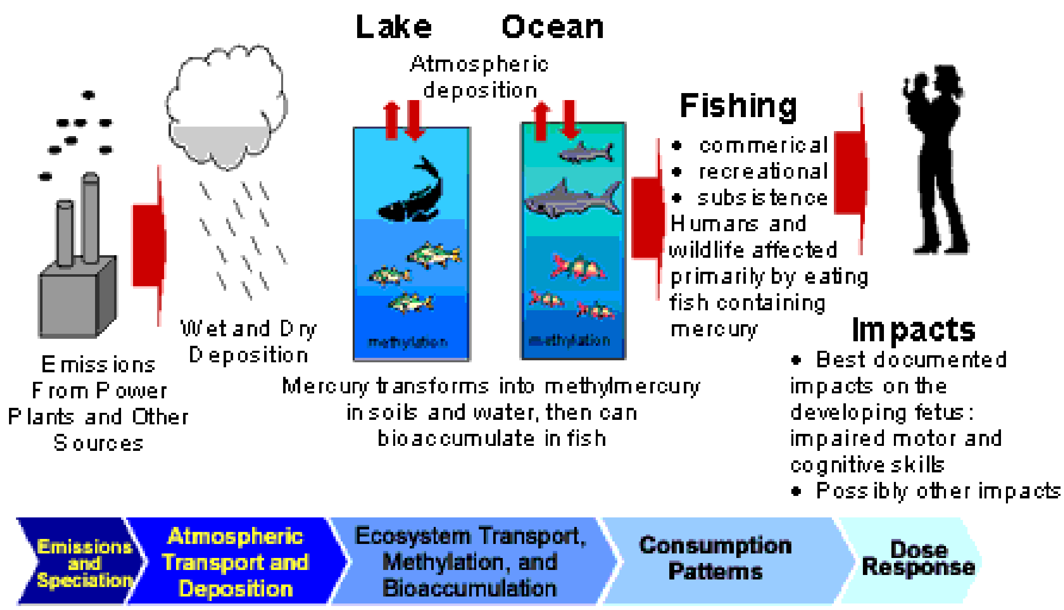
Coastal Waters are in Trouble

Pollution in coastal waters is bad in many areas, it is getting worse, and more and more areas are affected. According to A National Strategy to Restore Coastal and Estuarine Habitat:

1. 95% of San Francisco Bay's original wetlands have been destroyed.
2. 85% of Galveston Bay's sea grass meadows are gone.
3. More than 30% of Connecticut's coastal wetlands have been lost.
4. 25 square miles of coastal Louisiana wetlands disappear each year.
5. Oyster harvests in Chesapeake Bay plummeted from 25 million pounds to one million pounds in just 30 years.
6. The number of wild salmon returning to Maine's rivers has dropped 80% in the last ten years.

There are Many Types of Coastal Pollution.

1. Bacteria and viruses (pathogens).
2. Oxygen-depleting substances such as sewage, other carbon-based waste, and dissolved carbon-based material,
3. Toxic substances such as:
   (a) Heavy metals, especially in carbon-based compounds:
      i. Arsenic
      ii. Cadmium
      iii. Cobalt
      iv. Copper
      v. Lead
      vi. Mercury, especially methyl mercury
      vii. From Environmental Protection Agency: How Mercury Enters the Environment.
      viii. Manganese
      ix. Tin
      x. Selenium
      xi. Zinc
      xii. Uranium



   (b) Industrial waste products such as polychlorinated biphenyls, Polychlorinated biphenyls are mixtures of up to 209 individual chlorinated compounds (known as congeners). There are no known natural sources of PCBs. PCBs are either oily liquids or solids that are colorless to light yellow. Some PCBs can exist as a vapor in air. PCBs have no known smell or taste. Many commercial PCB mixtures are known in the U.S. by the trade name Aroclor. PCBs have been used as coolants and lubricants in transformers, capacitors, and other electrical equipment because they don't burn easily and are good insulators. The manufacture of PCBs was stopped in the U.S. in 1977 because of evidence they build up in the environment and can cause harmful health effects. Products made before 1977 that may contain PCBs include old fluorescent lighting fixtures and electrical devices containing PCB capacitors, and old microscope and hydraulic oils. From U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry ToxFAQs.

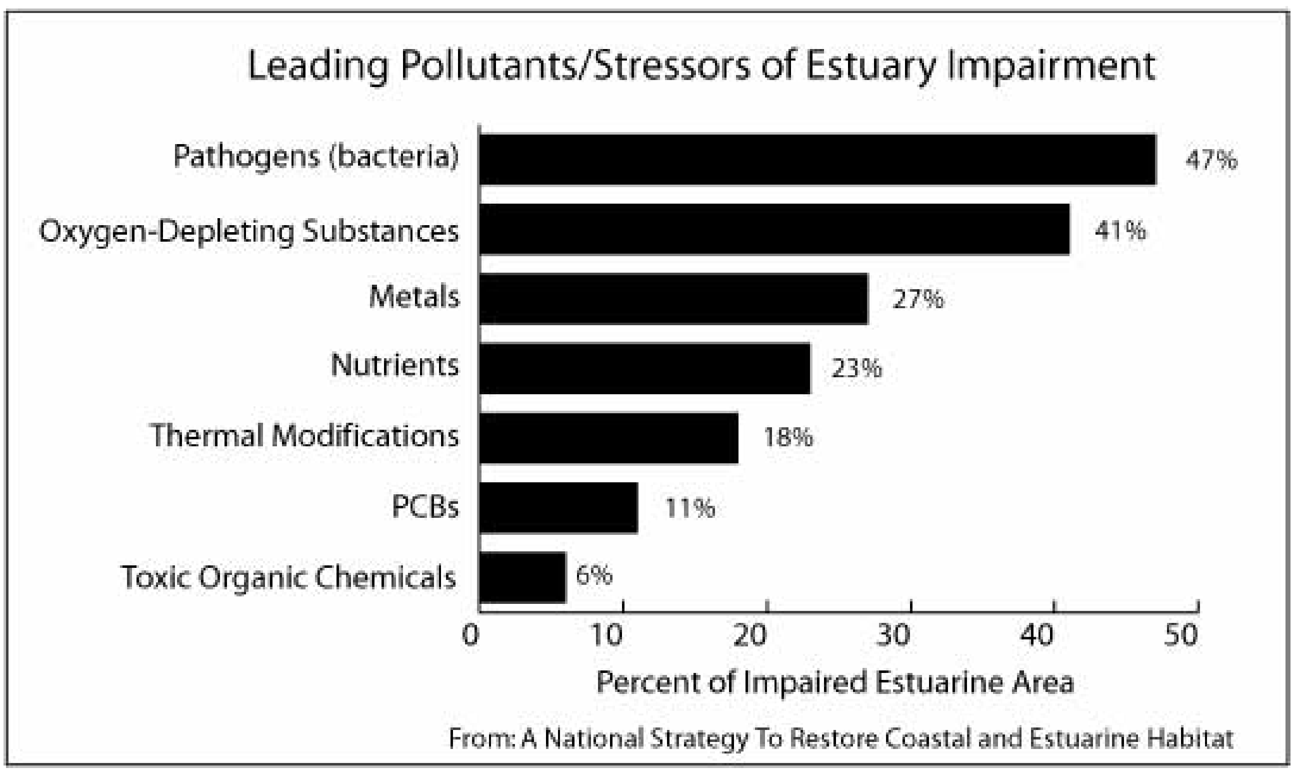
(c) Toxic carbon-based compounds (herbicides, pesticides),

4. Nutrients (nitrates, phosphates),
5. Hot water discharge from power plants,
6. Alien species, such as the European Green Crab and the aquatic weed Carcinus maenas on the US west coast.
7. Litter. There are three types:

(a) Monofilament fishing line, fishing nets, and tackle.
(b) Abandoned fishing boats, docks, and structures.
(c) Small objects, including plastic rings used to hold 6-packs of cold drinks, cigarette butts, and tires.

8. Noise, especially noise that interferes with marine mammals and other animals communications and hearing. The ocean environment has always included an abundance of natural noises, such as the sounds generated by rain, waves, earthquakes, and sea creatures. However, a growing number of ships and oil rigs, as well as increased use of sonar by navies and researchers, is adding to the natural noise that already surrounds marine life. Although noise in the sea has increased steadily since the Industrial Revolution, there is little information on exactly how noisy it has become or how marine mammals in particular react to the noise. Nevertheless, recent episodes in which dolphins and whales have beached themselves while human-generated sounds were being deployed nearby have raised questions about the impact of ocean noise. From National Academy of Sciences Report onOcean Noise and Marine Mammals

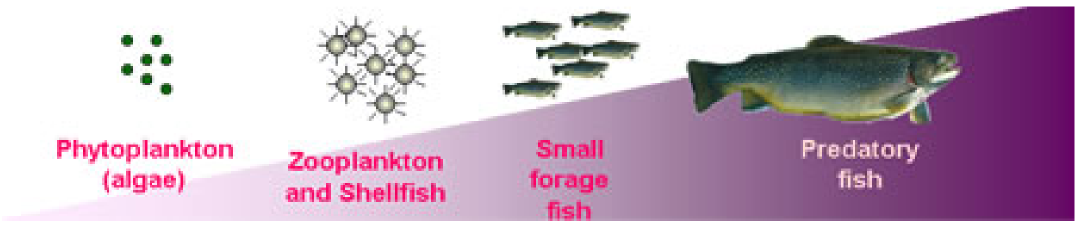
Top Seven Pollutants



Pollution has many consequences.

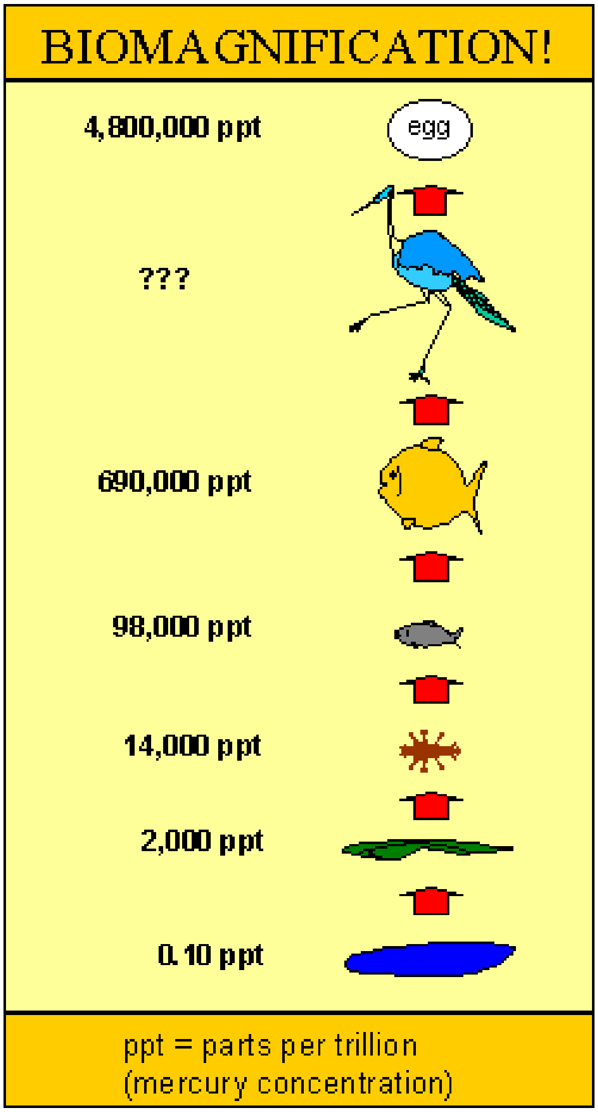
1. It may be concentrated to dangerous levels by marine animals such as shellfish. Eating polluted shellfish can cause serious illness (see Harmful Algal Blooms). Animals at the top of the food chain, such as tuna, have the greatest concentrations of some pollutants such as mercury. Note it is the concentration of the pollutant that is important, not the total amount in the animal. Phytoplankton have small concentrations, predators can have much higher concentrations. The increase in concentration of pollutants is called bio-magnification or bio-accumulation.

Table 17.1:



From Environmental Protection Agency: Methylmercury Exposure.

Table 17.2:



Mercury concentrations in parts per trillion increase as the trophic level of aquatic animals increases in south Florida, an region with high levels of mercury pollution. From US Geological Survey: South Florida Restoration Science Forum.

2. For a very interesting, well-argued study of mercury in the ocean, its occurrence in tuna, and the regulation of mercury exposure for pregnant women, read the Mercury Science Findings in People of the State of California vs. Tri-Union Seafoods (6.2 MByte PDF file). Superior Court Judge Robert L. Dondero finds methylmercury levels in ocean fish ‘‘virtually natural in origin,” and mercury alarm scientists have ‘‘credibility problems.” Finds study underlying EPA's mercury RfD confounded, unreliable and without ‘‘statistically significant relationship.” From Center for Science and Public Policy web page on Mercury.
3. Pollution may kill off a thriving tourist business in a coastal region.
4. Dangerous species may become common, causing health problems, and interfering with tourism and fisheries. A few years ago, a new organism was found in some estuaries along the east coast: Pfiesteria piscicida. It killed fish. It seemed to cause sores and memory loss in people who handled the dead fish. Where do these organisms come from? For more see the Pfiesteria web site.
5. It may kill marine life, e.g. birds caught in plastic rings used to hold 6-packs of cold drinks.

6. Large quantities of nutrients and carbon-based waste leads to plankton blooms. When the plants die, they sink to the bottom, decay, and reduce the oxygen in deeper waters, e.g. the Gulf of Mexico Hypoxia (dead) Zone caused by Mississippi River runoff.

Mississippi River Basin.

From US Environmental Protection Agency.

Sources of Coastal Pollution

Pollution sources are classified as **point sources** or **non-point sources** by the US Environmental Protection Agency. Information about pollution sources is included in their Fact Sheets.

Point Sources

Point sources are:

> Any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock concentrated animal feeding operation (CAFO), landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff. From EPA Glossary.
>
> Point sources generally enter receiving water bodies at some identifiable site(s) and carry pollutants whose generation is controlled by some internal process or activity, rather than weather. From US Environmental Protection Agency National Management Measures to Control Nonpoint Source Pollution from Agriculture.

Point sources include combined sewer overflows, concentrated animal feeding operations, sanitary sewer overflows, storm water, oil spills, industrial discharges; discharge from boats, and dumping of ballast water from ships.

Table 17.5:

Wisconsin Feedlot. The soil is wet from rain, urine, and manure. and it is a rich source of bacterial, viral, and nutrient pollution. From Clean Water Action Council of Northeastern Wisconsin, Inc.

Non-Point Sources

> Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. Technically, the term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. From EPA Polluted Runoff Background Paper.

Non-point sources include:

1. Runoff from farm lands and managed forestsin the coastal zone that carry fertilizer, excess nutrients, pesticides and herbicides, salts in irrigation water, and crop residues.

2. Runoff from agricultural areas (excluding concentrated animal feeding operations) that carries nutrients, animal wastes, manure, and pathogens (bacteria and viruses).
3. Runoff from coastal cities that carry trash, litter, heavy metals, carbon-based chemicals such as oil from highways, fertilizer and pet waste from backyards and sidewalks, and detergent (the most common pollutant).

Trash from land carried into the ocean by rains. Click on image for a zoom. FromDaniel Taylor, Synthesis Magazine.

Acid mine drainage.

Hydromodification. Hydromodification is one of the leading sources of impairment in streams, lakes, estuaries, aquifers, and other water bodies in the United States. Three major types of hydromodification activities change a waterbody's physical structure as well as its natural function. These changes can cause problems such as changes in flow, increased sedimentation, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic populations, and decreased water quality. The changes are:

1. Channelization and channel modification, including cutting new channels through barier islands, or closing such channels.
2. Dams.
3. Stream bank and shoreline erosion.

Marinas and boating facilities.

Marina Del Rey, California, a coastal lagoon turned into urban development and marinas.The area was originally known asBallona Lagoon. Click on image for a zoom. From Bruce Perry, California State University Long Beach. Rancho La Ballona was characterized by two great creeks; Ballona Creek running from the east to west and creating a great lagoon and Centinela Creek running from the northern hills to Ballona Creek ... As the 19th century came to a close, La Ballona was considered a ‘‘swamp” and the only activity occurred at the mouth of Ballona Creek where the squatter Will Tell opened a sea shore retreat that would ‘‘furnish sportsmen with board and lodging for man and beast.” From Del Rey Neighborhood Council.

Atmospheric deposition of sediments and chemicals carried by the wind.

1. Mercury in water comes mostly from the atmosphere.
2. 55% of mercury emissions are natural, from volcanoes and forest fires.
3. 42% are man made outside the USA.
4. 1% come from US power plant emissions.

Under some conditions, excess sand, silt, and clays (sediments) eroded from land, especially land denuded of plants that hold sediments. Mostly, sediments are needed by the coastal zone. Excess sediments that bury plants, or sediments in water that is historically sediment free, such as water near coral reefs, are pollutants.

Groundwater discharge which can include all types of pollutants, including water from faulty septic systems.

Solvents used to clean boats, anti-fowling agents leached from hulls. Anti-fowling agents are designed to be highly toxic to marine life that settles on to hard surfaces.

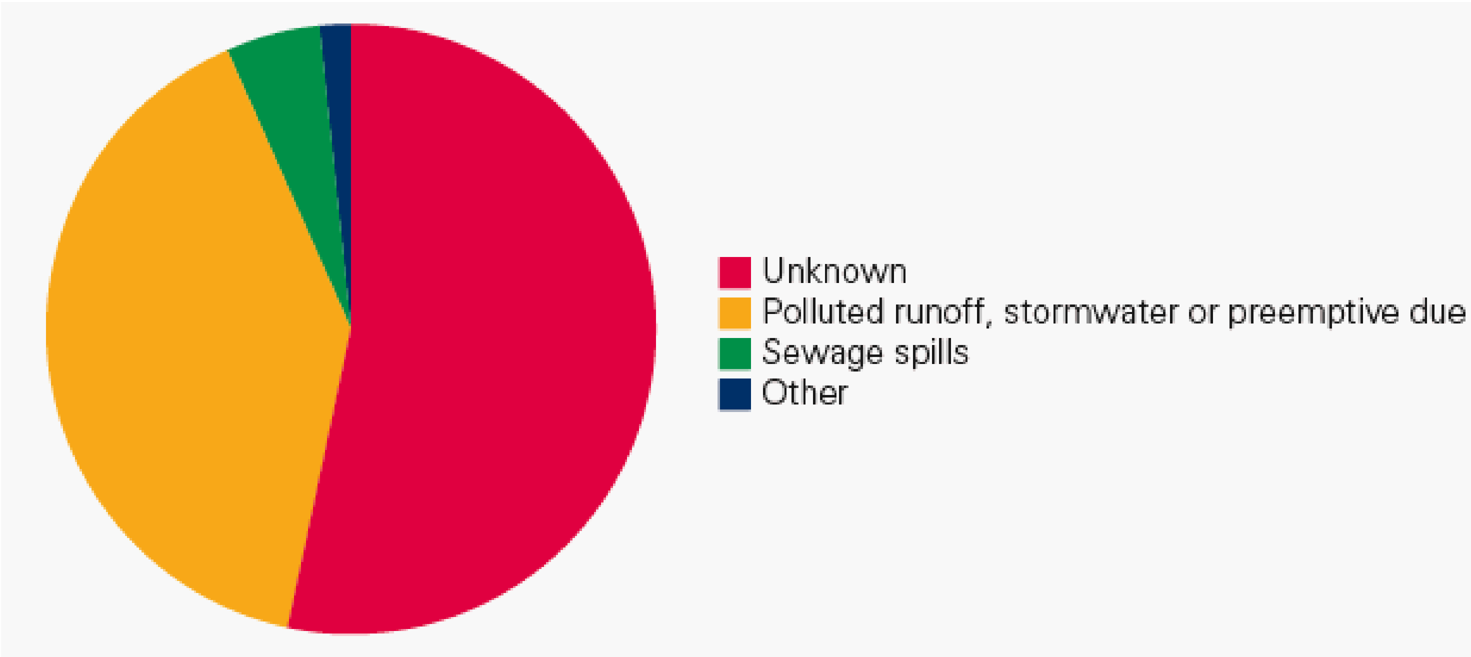
Trash dumped from ships, dropped on beaches, and washed into the ocean.

Beach Pollution

The most common sources of bacterial pollution at beaches and near-shore waters are:

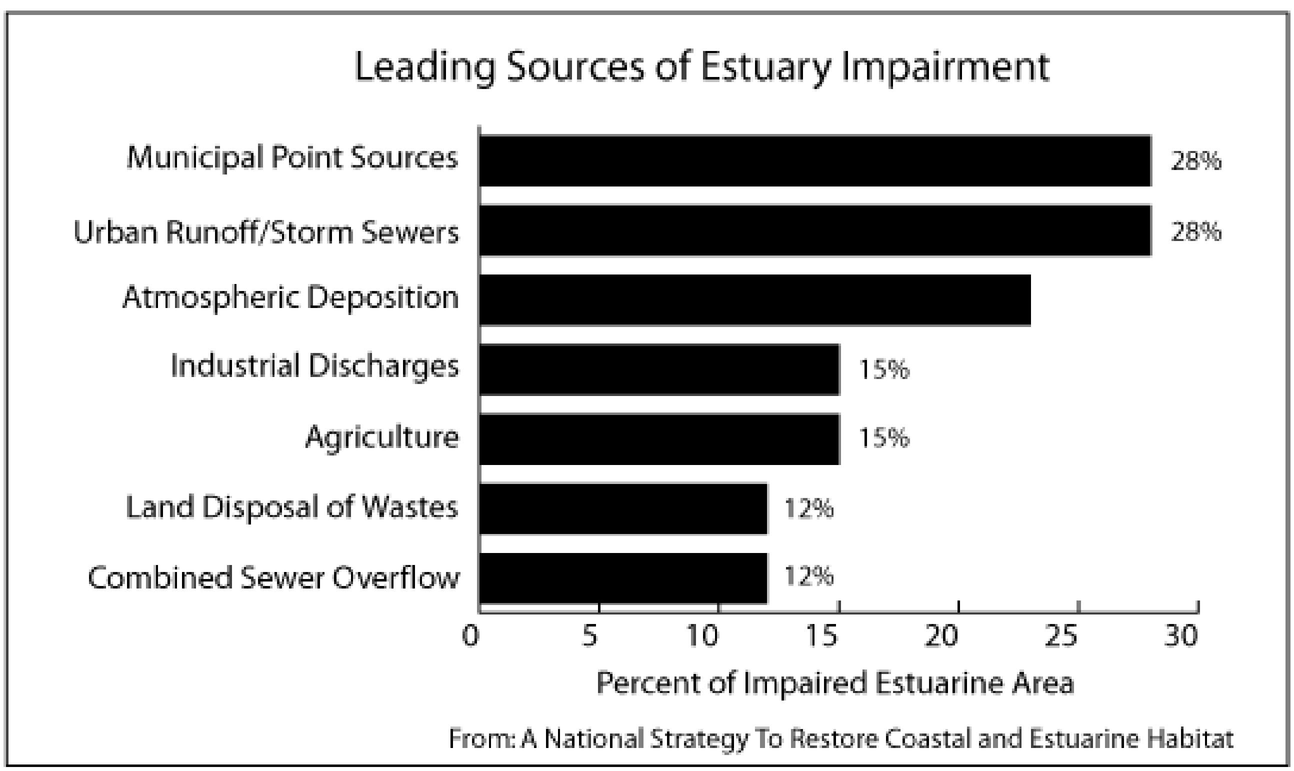
1. Unknown, very few governmental agencies track the source of pollution on their beaches.
2. Runoff from land, including urban areas and intensive farming operations. Runoff from urban lawns and streets contains waste from millions of pets. Pollution is greatest from areas with the largest percentage of impervious surfaces (roofs, paved streets and parking lots). A study conducted in South Carolina found that a watershed that was 22 percent covered by impervious surfaces had an average fecal coliform count seven times higher than a watershed that was 7 percent covered by impervious surfaces (Mallin, 2006).
3. Sewage spills and overflows, including spills caused by heavy rains overloading combined sewage systems (combination of street drains and sanitary sewage).
4. Boat spills and wildlife, although these are not very important.

Table 17.10:



Sources of bacterial pollution causing 25,643 days of beach closings at US vacation beaches in 2006. From Testing the Waters: A Guide to Water Quality at Vacation Beaches by the Natural Resources Defense Council (Dorfman, 2004).

Summary



Read this United States Geological Survey fact Sheet on Nitrogen in the Mississippi Basin-Estimating Sources and Predicting Flux to the Gulf of Mexico.

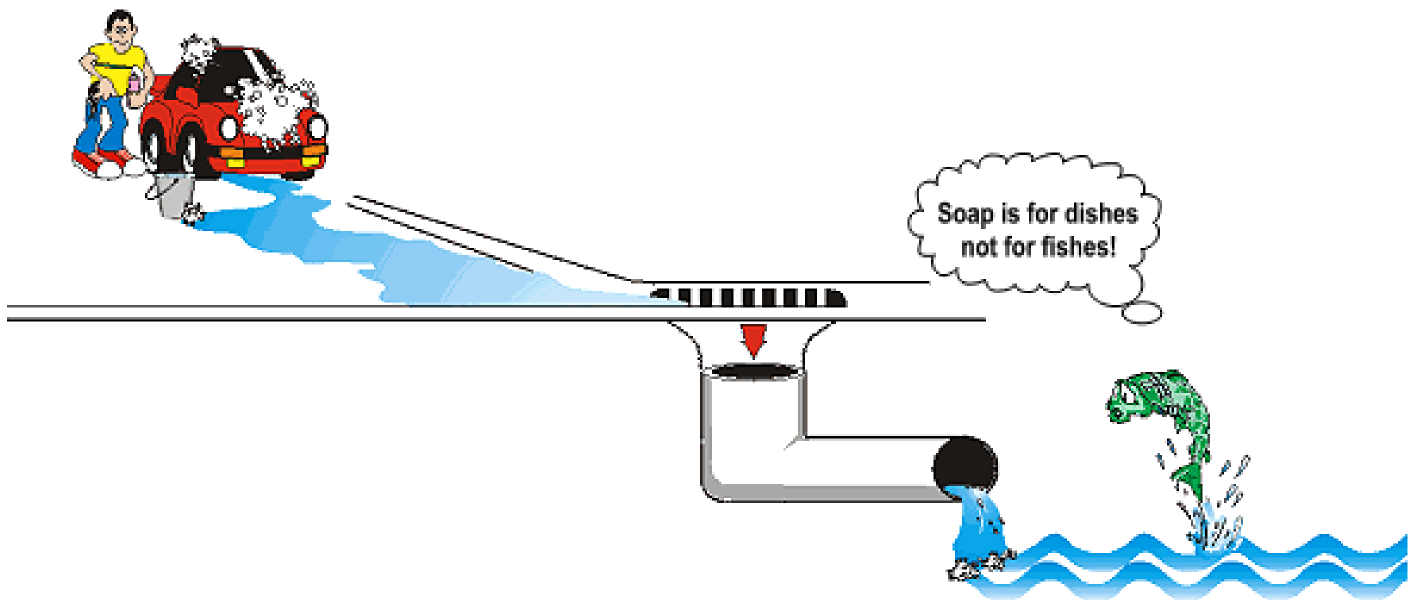
17.3 What Can I Do?

The Coastal Waccamaw Storm water Education Consortium has useful information.

> Good water quality depends on us, and we depend on good water quality. And ensuring good water quality starts with individuals like you! There are many things that you can do around your home and in your everyday life to help manage storm water and control nonpoint source pollution in order to protect water quality. Consider the impact on our local waters if everyone took these simple steps.

1. Remember, storm drains lead to the rivers, which lead to the sea. Never put anything into a storm drain.
2. Pet owners should pick up after their pets and dispose of pet waste in the garbage.
3. Don't litter.
4. Plant rain gardens, vegetated buffers, and maintain vegetation.
5. Properly maintain your septic system.
6. Maintain your car to prevent oil and fluid leaks.
7. Wash your car at a car wash or over the grass to prevent the soap and wash water from flowing into nearby storm drains.
8. Use fertilizers and pesticides sparingly and only as directed. Consider organic, non-toxic alternatives to these chemicals.
9. Do not allow yard waste such as leaves and grass clippings to blow into gutters or onto paved surfaces to be washed into storm drains.
10. Report erosion and sediment problems from construction sites.
11. Minimize impervious surfaces.
12. Get involved in local river and beach clean ups, and other projects that help protect water quality.

Table 17.11:



From Fort Worth Detergent is our Number One Pollutant

17.4 Fisheries Issues

Fish are Mostly Gone

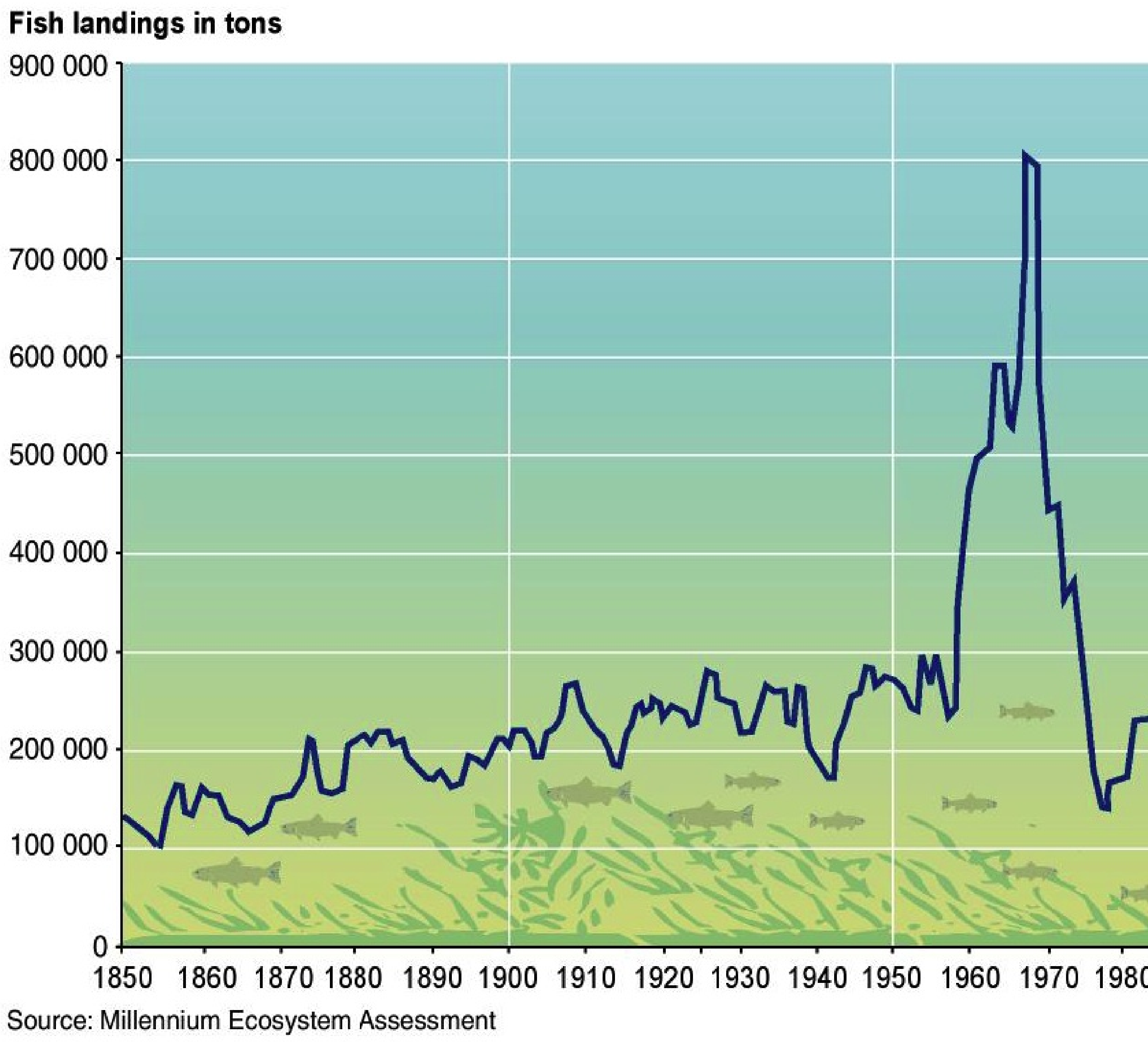
Most fish stocks throughout the ocean are over fished despite fisheries regulations. Over fishing has reduced the populations of fish, turtles, sharks, and whales to 0.1 – 40 percent of their values 50 to 100 or more years ago. Some popular fish, such as blue-fin tuna, are approaching extinction.

Read this very important article by Jeremy Jackson and colleagues on Historical Over fishing and the Recent Collapse of Coastal Ecosystems from Science (2001), Volume 293, pages 629 to 638, in which they show that "Historical abundances of large consumer species were fantastically large in comparison with recent observations."

> George Rose of Memorial University in Newfoundland has reconstructed the population size of cod back to 1505 when Europeans first dipped their hooks and nets in North American waters ... His best guess is that there were 7 million tonnes of cod swarming the banks and coasts of Canada in 1505, made up of several billion fish. By the time the cod moratorium was announced in 1992, there were just 22,000 tonnes left, one-third of 1 percent [0.3%] of the original population ... Andy Rosenberg and colleagues from the University of New Hampshire have taken a different approach to estimate the abundance of cod in grounds further south. They examined logbook records from the 1850s .... with 326 logbooks available for boats fishing all or part of time in the area ... Their best guess is that there were 1.26 million tonnes of cod on the shelf. The figure is in the same range as Rose's, given that the Scotian Shelf covers a smaller area and that by the 1850s, fishing had almost certainly significantly reduced the size of stocks from their pristine levels. The estimated stock size in 2002 was just 3,000 tonnes, one-third of 1 percent [0.3%] of the 1850s level. From The Unnatural History of the Sea (2007).
>
> The estimated combined weight of the adult cod population in 1992 was a mere 1.1 percent of its historic levels of the early 1960s. In 1992 the government finally closed the Banks altogether to allow the stock to recover. But by then it was far too late. Even if left alone, the northern cod may never recover. Industrial technology and human greed may have so decimated these hardy fish that they can no longer hold onto their ecological niche. The crash could be irreversible. From E Magazine A Run On The Banks.

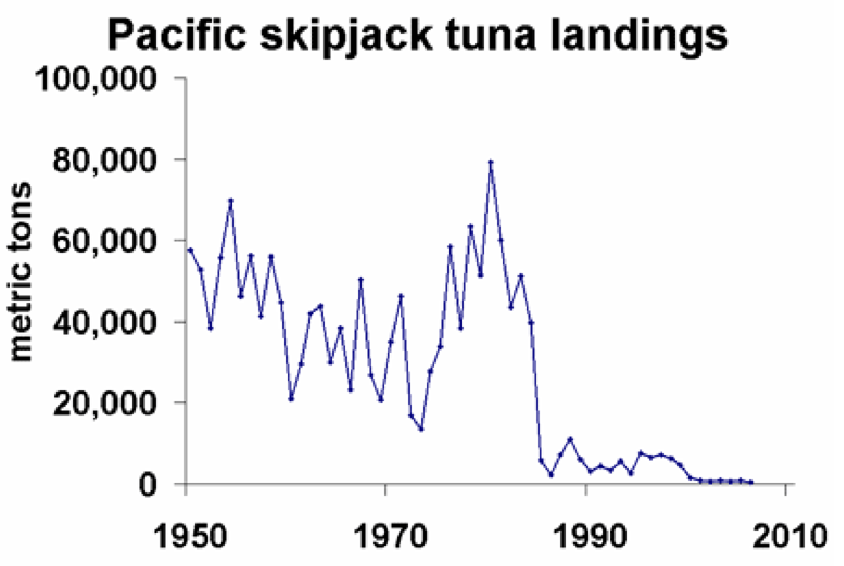
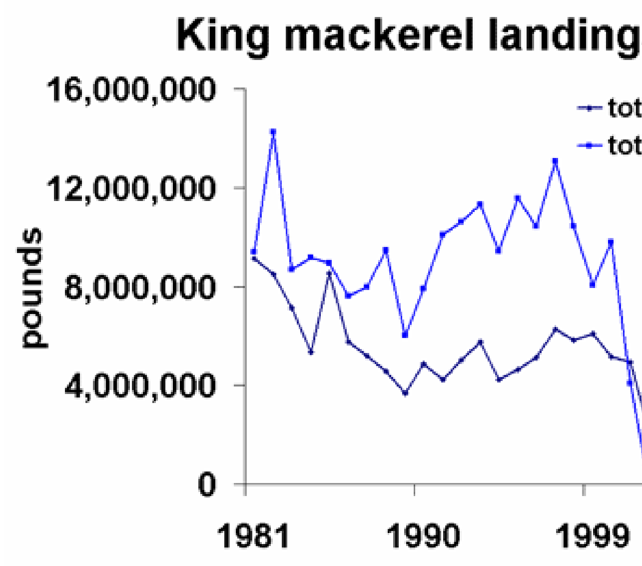
Table 17.12: (continued)

Table 17.12:



Cod stocks on Canada's East Coast have failed to rebound more than a decade after the fishery was closed. Orange roughy stocks in the southwest Indian Ocean were fished to depletion in three years by 40 vessels while negotiations to create a regional fisheries management organization (RFMO) were underway. Catches by European Union (EU) countries dropped 20 per cent between 1990 and 2002. From the Canadian governments Over fishing and Fishing Governance web site on State of the Global Fishery.

The surging popularity of sushi and sashimi has devastated the bluefin tuna. Overfishing has slashed populations in the Atlantic, Pacific and Indian oceans, pushing the species toward extinction. Regulatory bodies have failed to set sufficiently strict catch quotas, and illegal fishing is rampant. From Scientific American The Blue Fin In Peril.

What Was It Like Before Fish Were Exploited?

> It was almost like a hallucination. Immediate. A sense of dislocation. Something was awry... I had flopped overboard from a dinghy on a glassy Caribbean sea in the summer of the year 2000 and in an instant, apparently, slipped backward nearly half a century into an underwater realm that had not existed, so far as I knew, since the 1950s... Residents swarmed over me, welcoming me to the neighborhood, animals in numbers and diversity I hadn't seen in decades, not since Lyndon Johnson was president. Schools of yellowtail snappers and blue creole wrasses darted about in a frenzy. A squadron of glittering tarpon passed regally by, ... Green moray eels slid part way out of their crevice homes,... From *National Geographic:* *Cuba Reefs: A Last Caribbean Refuge*, February 2002.

> When I came to Texas in 1910, I could blindfold myself, get in a rowboat with no oars–just a push pole–push my way to the fishing grounds, and catch a hundred pounds or more of trout and redfish in a few hours using a twenty-foot cane pole, line, leader, and float for tackle. From Fishing Yesterday's Gulf Coast by Barney Farley.

> The abundance of sea fish are almost beyond believing. [Offshore of New England.] Francis Higgenson in 1629, in Kurlansky, Cod, page 70

There are two versions of an unexploited fishery, the one that existed before we began fishing.

1. An ecosystem dominated by great numbers of fish of all sizes, from small fry to large, top predators. This is the traditional pyramid with many small fish, fewer mid-sized fish, and still fewer top predators.

Table 17.13:

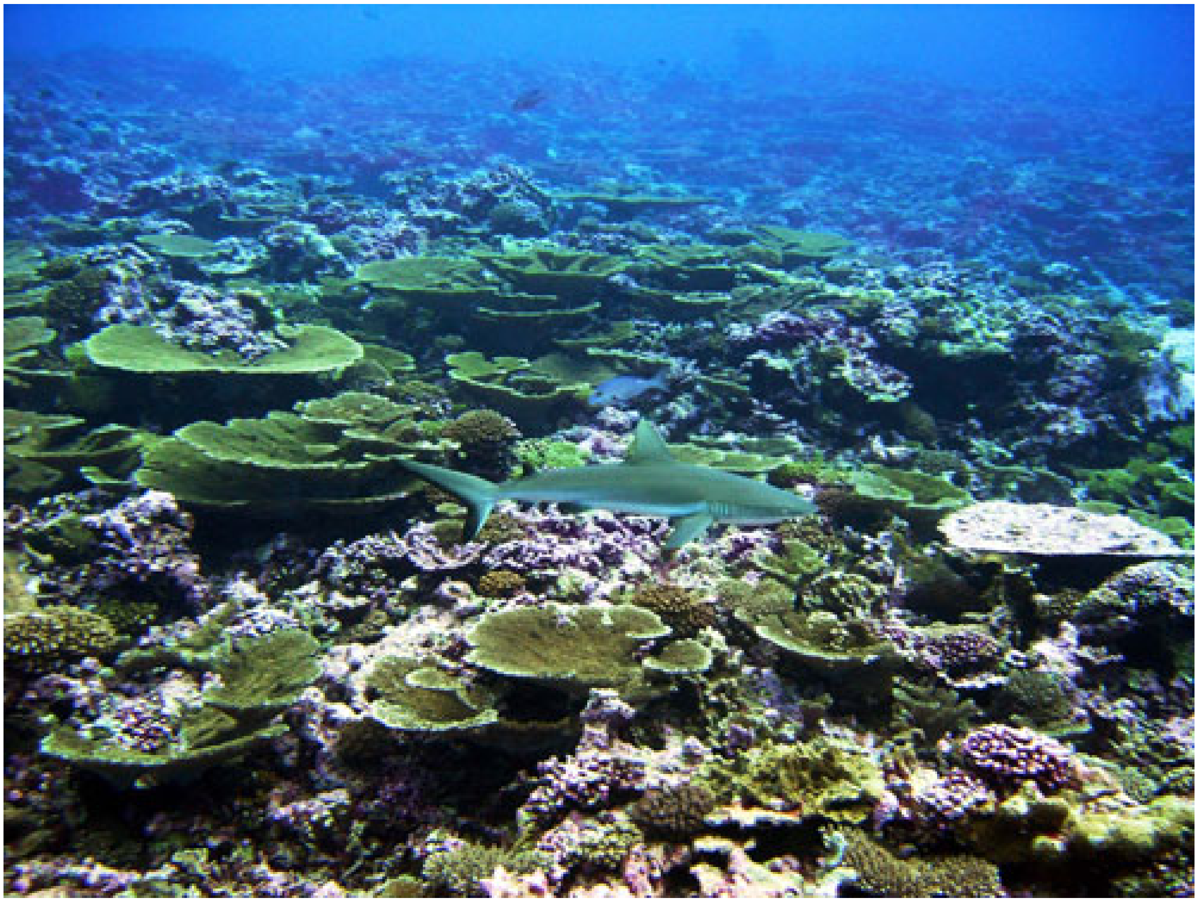
Table 17.13: (continued)

	Large numbers of fish at

Palmyra Island, an un-exploited ecosystem in the Pacific. The photo shows a school of convict surgeonfish swimming around dead coral off Palmyra Atoll. The plant-eating fish are known for keeping algae in check in coral reef ecosystems. This is the common view of a tropical paradise. From Explorations: Magazine of the Scripps Institution of Oceanography, Paradise Redefined.

2. An ecosystem dominated by top predators with very few other fish. This is the inverted pyramid recently discovered by Scripps scientists in remote coral islands in the Pacific.

Table 17.14:



The inverted pyramid ecosystem, dominated by top predators, a gray reef shark in this photo, and very few other fish. The photo was taken at Kingman Reef, an uninhabited, virtually undisturbed ecosystem. This too is a tropical paradise, but not one that was expected. From Explorations: Magazine of the Scripps Institution of Oceanography, Paradise Redefined.

How Important Are Fisheries to the Economy of Any Region?

Fisheries are not very valuable. For the entire United States, the total value of fish landed was only about 4% of the total value of livestock and poultry raised on the land. For Texas, the total value of fish landed was $0.19B in 1999 according to the Texas Almanac (page 124) while total cash receipts for livestock and products was $8.4B in 1999 (same, page 603). Thus for Texas the value of fish from the ocean was about 2.3% of the value of livestock from land.

In 2006, the total weight of all fish caught in US waters was 4,308,523 metric tons, worth $4.0 billion dollars. In Texas, the values were 53,130 metric tons worth $0.2 billion dollars. The NOAA Fisheries Statistics Division of the National Marine Fisheries Service (NMFS) has automated data summary programs that anyone can use to rapidly and easily summarize U.S. commercial fisheries landings.

Recreational fisheries are far more important. Recreational fishers caught 100,925 metric tons of fish in 2006. While this is only 2.3% of the commercial harvest, the large number of fishers, their use of hotels and restaurants in coastal areas, and their purchase of gear, make important contributions to the coastal economy. 13 million saltwater fishers made 89 million fishing trips and caught 475 million fish in 2006.

> Every year, more than 12 million Americans enjoy wetting a line in our oceans and along our coasts. More than just a traditional American pastime and contributor to conservation, saltwater recreational fishing is a major economic driver generating more than $30 billion in economic impact and supporting nearly 350,000 jobs nationwide. From National Marine Fisheries Service.

How Many Can Now Be Caught?

The basic question is: How many fish can be harvested from the sea? The answer is not simple. Some fish stocks are declining. Is the decline due to over fishing? Is it due indirectly to fishing for other types of fish? Or is it due to the natural variability of the stock? If it is due to over fishing, what can be done? Reduce the number of ships? Limit the fishing season?

Because the answers are somewhat fuzzy, fishery regulatory bodies always err on the side of over fishing. Or, in some instances, the regulatory bodies ignore the answers.

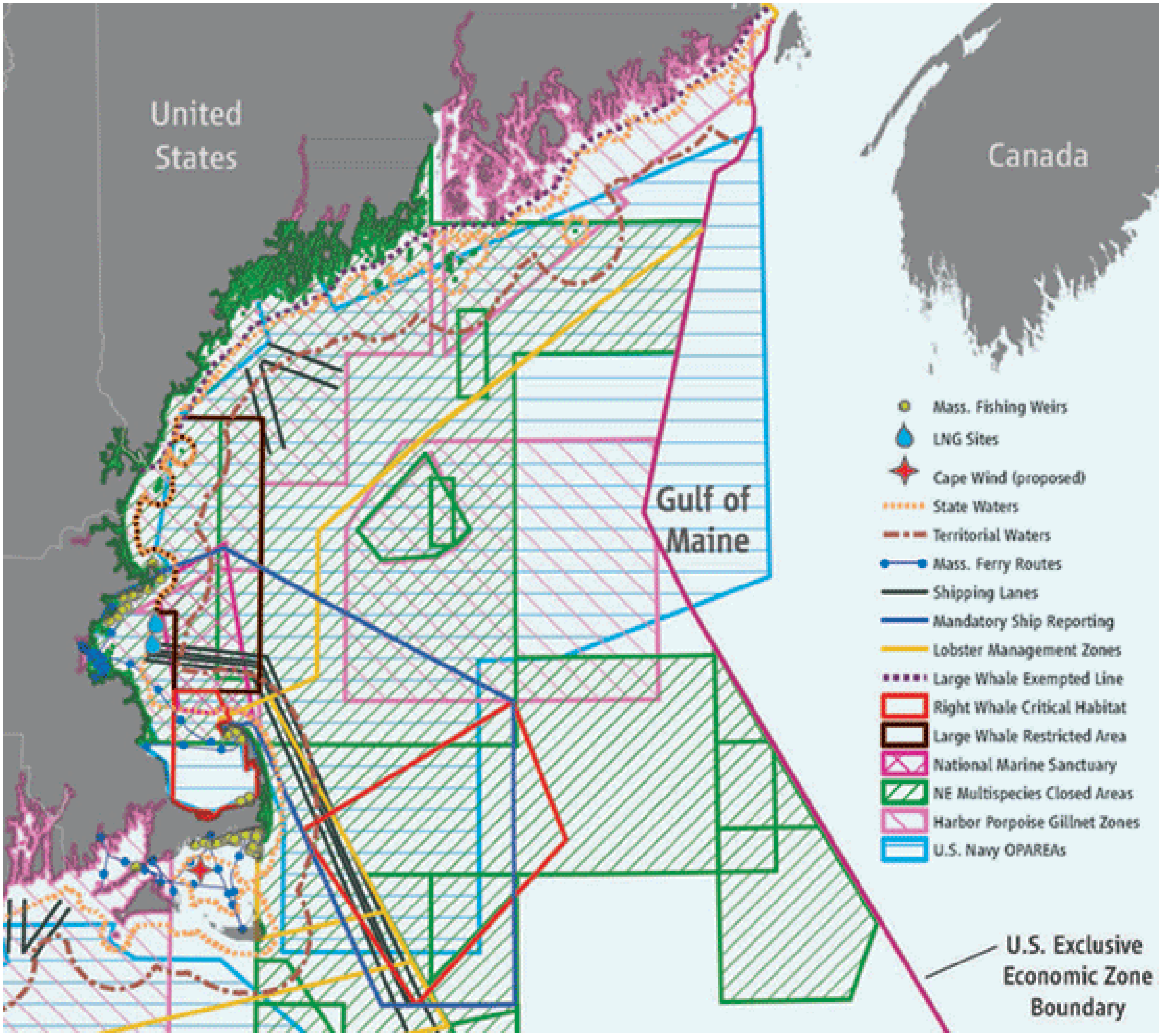
Who Regulates Fishing?

In the United States, states regulate fishing from the coast out to 3 nautical miles, except Texas and West Florida, who regulate fishing to 9 nautical miles. The federal government regulates fishing from 3 nautical (or 9 nautical miles) to the outer limit of the Exclusive Economic Zone, 200 nautical miles. See the web page on the Coastal Zone.

Unfortunately, no one is in charge.

> Over 20 federal agencies operating under dozens of laws regulate activities, support ocean-based commerce, and protect marine species and habitats in the territorial sea and EEZ. These agencies separately manage parts of marine ecosystems, without any systematic effort to coordinate their actions for the public good. From Turnipseed et al (2009).

Table 17.15:



A cacophony of activities, most regulated by separate federal agencies, crowd ocean waters in the Gulf of Maine. A federal public trust doctrine extended to all U.S. ocean waters would identify these agencies as trustees of the U.S. ocean public trust, unifying them for the first time under a common mandate to manage marine resources sustainably. LNG, liquified natural gas; OPAREAs, Operating areas. From Turnipseed et al (2009).

In international waters, beyond 200 nautical miles, some fisheries are regulated by international treaty organizations such as theInternational Commission for the Conservation of Atlantic Tunas, which has attempted, withlittle success, to regulate the bluefin tuna catch in the Atlantic and Mediterranean. The Inter American Tropical Tuna Commission has been almost as unsuccessful regulating tuna fishing in the eastern Pacific, from the American coast to 150°W and from 50°S to 50°N.

Unfortunately, illegal fishing is very common, and many fish stocks are not regulated.

> On a standard 5-7 week fishing trip these poachers might expect to take anything from 500 to 800 tonnes . You're talking about several million dollars worth of fish for a month's fishing, which means that you can pay off a boat in a week or two. From Television Trust for the Environment Earth Report.

Table 17.16:

The rogue fishing vessel Viarsa 1 fleeing the Australian Fisheries and Customs patrol vessel Southern Supporter after it was found fishing illegally in Australia's sub-Antarctic waters. The ship was captured after a 20-day chase through high seas as the ship tried to return at maximum speed to Uruguay. The chase was documented in the best-selling book Hooked: Pirates, Poaching and the Perfect Fish by Bruce Knecht. Photo from Coalition of Legal Toothfish Operators.

Illegal, unreported and unregulated fishing, and its adverse impacts on national and regional efforts to manage fisheries in a long-term sustainable manner, is one of the main problems facing capture fisheries. From State of World Fisheries and Aquaculture 2006, Food and Agriculture Organization FAO.

Fisheries Policy Issues

Why Are Fish Gone? Here are some factors that have led to the decline of fisheries in many areas of the world, as outlined in Empty Oceans, Empty Nets, written by Habitat Media and in the American Association for the Advancement of Science's publication on Marine Fisheries, Population Consumption: Science Policy. The Monterey Bay Aquarium has similar information on Fisheries in Trouble.

The problems include soaring demand, improved technology, government subsidies, poor regulations, reduced fish stocks, bycatch, and destruction of bottom organisms and habitat by bottom trawling. Essentially, fish have nowhere to hide.

Population Pressure

> Fish provide a vital source of food for hundreds of millions of people worldwide. Overall, the marine catch accounts for 16% of global animal protein consumption. In general people in developing countries rely on fish as a part of their daily diets much more heavily than those residing in developed countries. For example, fish accounts for roughly 29% of the total animal protein in the diet of Asian populations, but only 7% for North Americans. The use of fish as a source of food rose from 40 million tons in 1970 to 72 million tons in 1993. Population is by far the most important factor in this burgeoning demand, accounting for roughly two thirds of change in total demand. At current rates of world population growth, the total world supply of food fish (marine, freshwater, and aquaculture) would have to grow from roughly 72 million tons in 1993 to 91 million tons by 2010 to maintain today's per capita fish supplies, according to FAO. From: American Association for the Advancement of Science:Marine Fisheries, Population and Consumption: Science and Policy Issues.

Factory Trawlers

To meet the demand for more fish, the fishing industry has turned to larger, more efficient ships, the most important being thefactory trawlers and ships.

> *Vladivostok-registered Kapitan Nazin, [is] one of the largest factory trawlers in the world. The Russian ship is one of three identical craft - each 347 feet (105 m) long and 10,000-tons displacement - built in Spain in 1993. They are classified by Det Norske Veritas (DNV) to withstand ice to Class 1B and operate year-round off the Siberian coast in the Sea of Okhotsk. The Kapitan Nazin and its 165 crew can process 125 tons of frozen product per day and store up to 3,200 tons in its refrigerated hold before off-loading at sea to a freighter.* [Thousands of such trawlers are fishing at sea, but not as many as conventional trawlers.] From Cascade General, Portland Shipyard press release from 1999. But what the factory trawlers lack in numbers they more than made up for in catching power. So awesome was this power in the early years of their prime (and so good was the fishing) [about 1965-70] that it is perhaps best describes by hypothetical analogy to dry land. First, assume a vast continental forest, free for the cutting or only ineffectively guarded. Then try to imagine a mobile and completely self contained timber-cutting machine that could smash through the roughest trails of the forest, cut down the trees, mill them, and deliver consumer-ready lumber in half the time of normal logging and milling operations. This was exactly what factory trawlers did – this was exactly their effect on fish – in the forests of the deep. From William W. Warner, 1983, Distant Water, The Fate of the North Atlantic Fisherman, page viii.

The largest factory trawler is the $65 million American Monarch, 340 feet long and displacing 6,730 tons. It can net and process about one million pounds (500 tons) of fish per day.

F/V ALASKA OCEAN. The GPA designed conversion of the 376' Alaska Ocean, the largest US flagged factory trawler in the fleet, was completed by Ulstein Hatloe AS, Norway, for Alaska Ocean Seafood LP. From Guido Perla & Associates.

Improved Technology

The most important improvement was the invention of frozen foods by the inventor and fisherman Clarence Birdseye. The invention enabled the distant water fisheries by factory trawlers. Trawlers freeze fish at sea, and they can travel for many months away from their home port. Trawlers from any country can fish anywhere in the world. Before the invention of frozen food, fish could be preserved only three ways:

1. Air drying or smoking. Fish were taken ashore, filleted, and dried or smoked on racks. This takes months of work, and limits the amount of fish that can be preserved.
2. Salting. "Salt preserves fish by removing water from the flesh and tying up the remaining water so that spoilage organisms cannot use it for growth. If enough salt is used, the fish may keep for as long as a year in a cool, dry place. Salting is one way to store fish until you are ready to smoke or pickle them." From Michigan State University Extension.
3. Preserving on ice. Fish are caught and placed on ice in the hold. Because cod kept at 0°C, the melting point of ice, will be virtually uneatable after fifteen days, this greatly limited the distance fishing boats could travel, catch fish, return, and get the fish to market. Trawlers could fish in waters only a week away from their home port, a distance of about 1500 nautical miles.

Table 17.17:

Left: Clarence Birdseye in his office. From Birds Eye Foods.**Right**:

Frozen fish fillets. From BlueWater Seafoods, Quebec, Canada.

Bycatch

Although commercial fishing fleets target only a few valuable species of fish, they kill and waste billions of pounds of unmarketable marine species each year. When the catch is hauled aboard, the non-commercial marine life–"bycatch"– is separated out and thrown back into the ocean dead. Bycatch can be fish with no commercial value, juveniles of marketable species, sea turtles and birds, marine mammals such as seals, dolphins and whales, and many other forms of ocean life.

1. According to a United Nations report, commercial fisheries discard an average of 54 billion pounds of fish bycatch each year [about 27 million metric tons].
2. As many as 40,000 sea turtles and more than 200,000 albatross are caught each year on longlines.
3. In 2000, over 200 billion pounds of marine life were brought to market for food. Estimated bycatch equaled 21% of the total catch.
4. Globally, shrimp trawlers catch approximately 22 billion pounds of bycatch each year – almost half of all bycatch.
5. Long line fishing fleets, towing miles of cable strung with thousands of baited hooks intended for tuna, swordfish, and Patagonian toothfish (Chilean Sea Bass), kill tens of thousands of albatross each year, which get caught on hooks as they dive for bait.
6. In 1992 the Alaska fishing fleet threw back 442 million pounds of bycatch, almost twice the amount of fish landed by the entire domestic fishing effort in New England that year.
7. For every pound of shrimp caught in the Gulf of Mexico, between four and eight pounds of marine bycatch is discarded.
8. For finfish, the ratio of bycatch to target fish can be as high as 11:1 because the bycatch is either too young, out of season, or the vessel has no permit to keep it. In 1998, U.S. pelagic Atlantic longlines fishing discarded 22,536 sword fish, 1,274 blue marlin, 1,485 white marlin, and 1,304 bluefin tuna as bycatch.

From:Conserve Our Ocean Legacy.

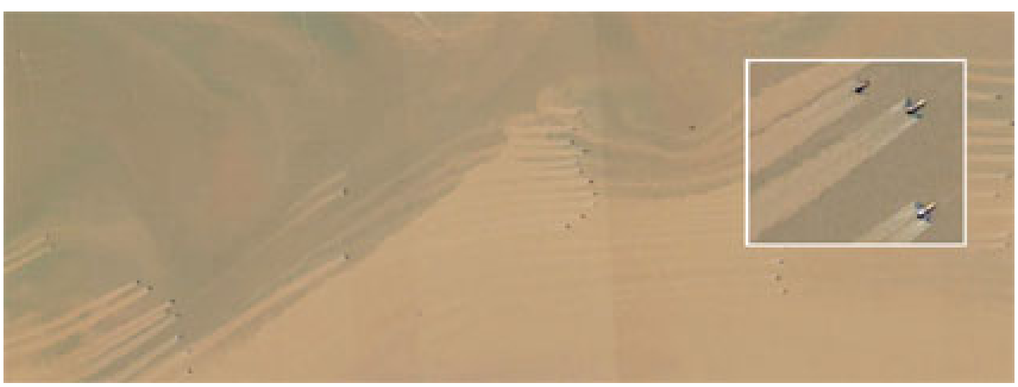
Pollution and Habitat Loss

1. Coastal Pollution. Coastal waters provide critical spawning, nursery or other habitat for many commercially important marine fish populations. These waters are under a multitude of assaults that stem principally from human activities on land. For example, roughly 80% of marine pollution is

estimated to come from land based sources. Development along the coast has destroyed an estimated 50% of all coastal wetlands worldwide. From: American Association for the Advancement of Science:Marine Fisheries, Population and Consumption: Science and Policy Issues.

2. Trawling and Dredging for Fish. The National Academy report on Effects of Trawling and Dredging on Sea-floor Habitat notes:
   (a) A single passage of a scallop dredge can destroy or damage living maerl, plants, and animals to a depth of 10 cm, and the track remains visible for 2.5 years.
   (b) Trawled sea floor areas have a 75 % reduction in total productivity.
   (c) In the Gulf of Mexico, bottom trawling for shrimp scours 255% of the sea floor each year. This means that every square meter of sea floor out to depths of 90 meters is trawled 2.5 times a year on average. Many studies report that repeated trawling and dredging causes a shift from communities dominated by species with relatively large adult body size toward dominance by high abundances of small-bodied organisms. Intensively fished areas are likely to remain permanently altered, inhabited by fauna that readapted to frequent physical disturbance. Specie richness (the number of species per unit area) and evenness (the relative abundance of resident species) – two measures of species diversity – can decline in response to bottom fishing..." The percentage of area trawled off New England exceeded 307%, that is, each square meter of the sea floor was trawled or dredged more than three times each year (Figure B2 of the report). A new study by the National Academy of Sciences [Effects of Trawling and Dredging on Seafloor Habitat] released today says that bottom trawling, a method of fishing that drags big, heavy nets across the sea floor, is killing vast numbers of marine animals. Coming after years of declining U.S. fisheries, the report finds that bottom trawling damages the habitat where juvenile fishes hide from their predators, and can significantly alter the marine ecosystem. From Effects of Trawling and Dredging on Seafloor Habitat. Committee on Ecosystem Effects of Fishing. National Academy Press, 2002. disturbance to sea-bottom ecosystems that they leave in their wake." From Anonymous (2007). "Snapshot: Ghosts of destruction." Nature 447(7141): 123-123.

Table 17.18:

	"Shrimp trawlers (see inset) off the coast of China. The long plumes of sediment churned up by their nets — 'mud trails' — are a highly visible sign of the

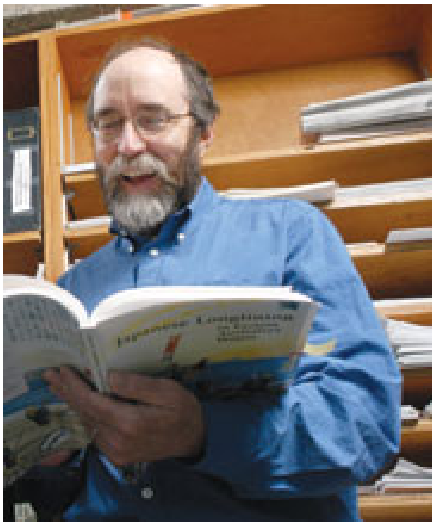
Government Policy.

1. (a) Subsidies for fishing industry. Government subsidies have lead to overcapacity in all important fishing areas. At its core, the crisis in over fishing stems from the fact that the world now has a

substantial overabundance of fishing capacity. Industrialized fleets aided by sonar, sophisticated satellite technology and highly efficient gear are now capable of fishing out vast areas of the ocean in very short order. The predictable results of overcapitalized fleets have been over fishing and depletion of stocks as well as substantial economic losses. FAO estimates that to rehabilitate fisheries to 1970 abundance levels and catch rates would require the removal of 23% of the existing gross weight tonnage of the world's fleet. Governments worldwide, anxious to preserve employment in fishing and shipbuilding and ameliorate the economic disruption caused by over fishing, have subsidized economic losses in the fisheries sector to the tune of $54 billion a year, according to FAO. Such subsidies serve to perpetuate over fishing and economic distress in the fishing sector. From American Association for the Advancement of Science:Marine Fisheries, Population and Consumption: Science and Policy Issues.

(b) Failure of Fisheries Scientists to Provide Accurate Advice. Ransom Aldrich Myers (1952–2007) was one of the first to notice that over fishing of cod offshore of Newfoundland, Canada, not the voracious seals, cold temperatures and other excuses invented by an agency that, by caving in to industry pressure, had failed to protect this vital resource and the province that depended on it. He was a leader among the handful of Department of Fisheries and Oceans (DFO) scientists who published evidence that excessive fishing was the sole cause of the stock's collapse. Unsurprisingly, given the press and public reaction to these papers, Myers was reprimanded by his superiors. He took refuge in academia, taking in 1997 the Killam Chair in Ocean Studies at Dalhousie [university]. From there, aided by colleagues and several brilliant graduate students, he published a series of papers showing that politically motivated, slothful optimism had masked the systematic destruction of marine resources, and marine biodiversity in general — not just in Canada and its marine jurisdictions, but the world over. These papers, again based on judicious analysis of existing time-series data, documented the worldwide depletion, through industrial fishing, of skate, sharks, large bottom fishes and, finally, large pelagic fishes such as marlin and tuna. Each new paper baited the staff of yet another agency into angry rebuttals. Myers had the thick skin required for such acrimonious debates. Once, when asked about the controversy that one of his papers had generated, his response was simply: "They are wrong, and I am right! In the process, Myers helped to found fisheries conservation biology. This discipline is devoted to identifying exploited fish populations and species threatened with extinction, and suggesting measures for rebuilding them, along with the ecosystems in which they are embedded. Correspondingly, its primary clients are not the owners of trawlers, longliners, purse seiners and other industrial vessels, but national and international agencies mandated with maintaining marine biodiversity and ecosystems, and the many benefits they provide for society as a whole. From Pauly (2007). Obituary: Ransom Aldrich Myers (1952-2007). Nature 447 (7141): 160-160.

Table 17.19:

	Ransom Aldrich Myers, fisheries scientist who dared to be right.

(c) Failure to regulate fishing. In principle, fish are protected everywhere: Freedom of the high seas" is a principle considered by a few to mean that the high seas are res nullius or "without law" and beyond the jurisdiction of any nation State except that of the flag state. Res nullius is an antiquated concept. In fact, customary and conventional international law indicate that the high seas and its resources are subject to res communis or the "law of the commons". Numerous treaties, including the United Nations Law of the Sea Convention (UNCLOS), restrict the use of the global ocean commons to that which is "reasonable" and does not infringe on the rights of others. "Freedom of fishing" for example, is subject to a whole host of conditions, indicative that the world community considers high seas fishing resources to be common property resources. FromInternational Law Governing Driftnet Fishing On the High Seas, Earthtrust. In practice, the history of fishing regulations is mostly a history of failure. Governments cannot agree on sustainable levels of fishing, leading to over fishing in almost all areas. Fish in many areas beyond the 200 mile Exclusive Economic Zones of coastal countries often have little protection despite the UN Convention on Fishing and Conservation of the Living Resources of the High Seas (1958). Fishing ships move to countries that do not enforce the international treaties. Or countries ignore international law. For example Despite the 1989 UN driftnet resolution (44/225) prohibiting further expansion of driftnet fishing it was reported that Taiwan expanded its operations in the Atlantic Ocean and that France increased its fleet from 37 driftnet vessels in 1989 to 78 vessels in 1991 in the Northeast Atlantic. From Earthtrust. Alaska does a better job of regulating fisheries than does Texas. Every body of water in Alaska has its own regulations. My guess is that when you live in a climate as severe as coastal Alaska, you develop an extra-sensory consciousness of the environment. You cannot help but notice the entire balance of nature sagging under the weight of man. It's almost as if the general population embraces rather than challenges the regulations Fish and Game have designed for conservation of resources. — Everett Johnson, Texas Salt Water Fishing, October 2006, page 5.

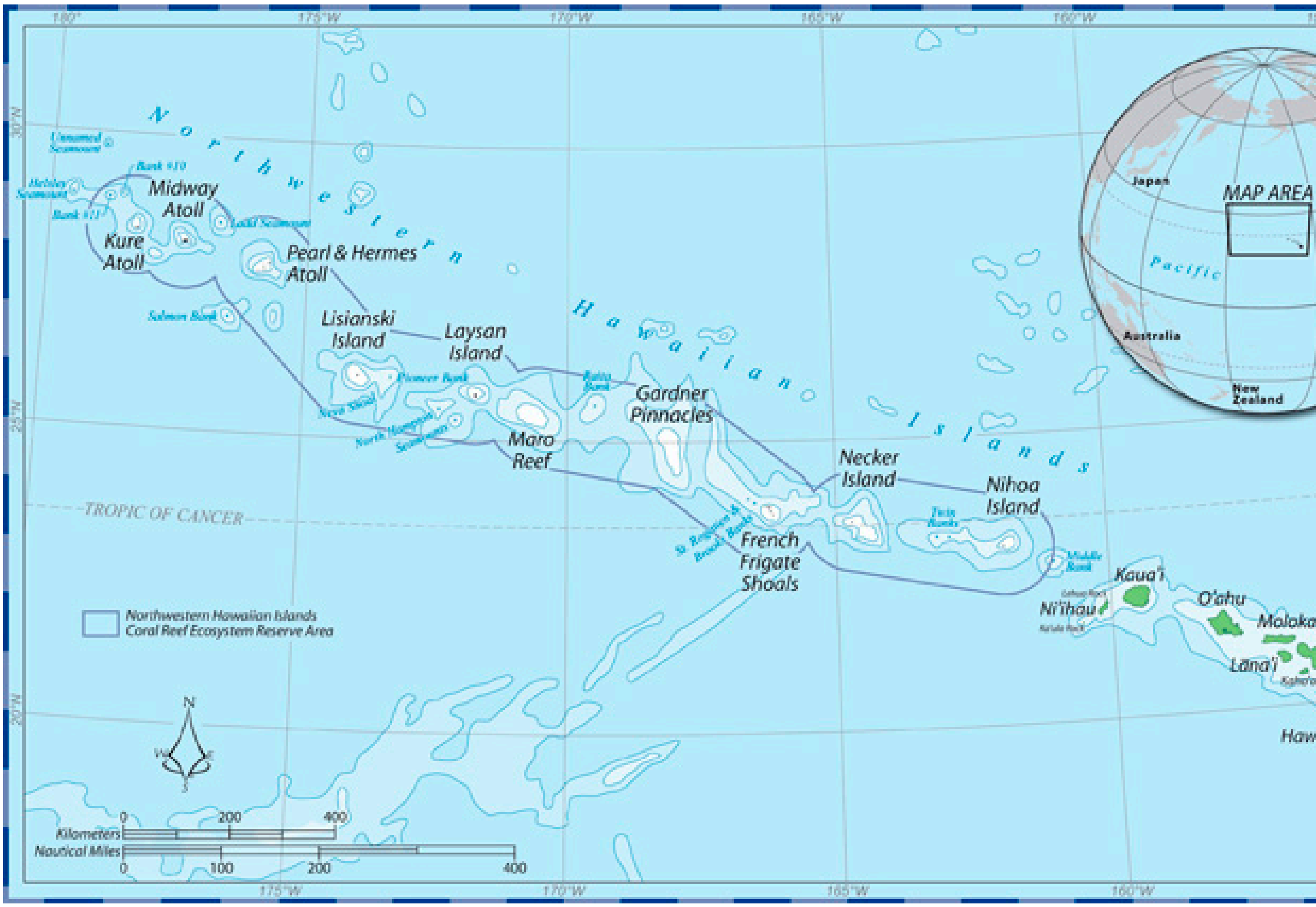
Solutions

1. Set up marine protected areas.
   (a) New Zealand closed to bottom trawl fishing methods, including dredging seven Benthic Protection Areas within their Exclusive Economic Zone. The area comprises more than 1.2 million

square kilometers of seabed. The area is 32% of the seabed in their exclusive economic zone, 52% of their seamounts, and 88% of their hydrothermal vents. Fishing within 50 meters is deemed to be touching the seabed and is a serious criminal offence, and will attract a fine of $100,000 and the vessel will be seized.

(b) The United States created the largest fully protected ocean conservation area in the world, the Papahanaumokuakea Marine National Monument in the Northwestern Hawaiian Islands.

Table 17.20:



Northwest Hawaiian Islands Papahanaumokuakea Marine National Monument. From NOAA Papahanaumokuakea Marine National Monument.

(c) California has set aside 203 square miles of Marine Protected Areas along the California coast. Of these, 85 square miles are Marine Protected Reserves that are are no take zones in which some commercial and recreational fishing is prohibited. Unfortunately, mostallow recreational taking of many species of fish, and shell fish, including red abalone, chiones, clams, cockles, rock scallops, native oysters, crabs, lobster, ghost shrimp, sea urchins, mussels, and marine worm and finfish. The Marine Protected Reserves are relatively small, extending about five nautical miles along the coast and out three nautical miles. The limits are lines of latitude and longitude, allowing easy determination by fishers and enforcements agencies. The California Department

of Fish and Game has a brochure listing the areas.
   (d) Hawaii has set aside a few small Marine Life Conservation Districts where most or all marine life is protected.

2. Reduce coastal development and protect lagoons and estuaries, the nurseries of many marine species. The pages on Coastal Pollution Policy Issues outlines ways these areas are being protected.
3. Reduce the number of fishing licenses. The State of Texas has been buying back thousands of shrimp fishing licenses to reduce the number of boats trawling for shrimp. "Texas Parks and Wildlife Department has retired 1,187 of 3,231 licenses on the books at a cost of $7.2 million. The overall number of inshore shrimp vessels in Texas waters has decreased from around 2,100 down to around 1,200 since the buyback program began." TDPW. By 2007 less than 700 shrimping vessels are still eligible for shrimping activity, and only 138 were active on the first day of the shrimping season, down from 886 shrimping vessels active on the day of the shrimping season in 1995– Coastal Conservation Association and Houston Chronicle.
4. Require Turtle Excluding Devices and Bycatch Reduction Devices on trawls. This reduces the by catch of turtles and other larger marine animals from shrimp trawls. The Bycatch Reduction Devices must reduce bycatch of fin fish by 30%.
5. Think locally, don't eat endangered fish. Which fish should we eat, which should we avoid because they are over fished or because fishing harms the environment? See the Monterey Bay Aquarium's *Seafood Watch*, their list of fish to eat or not eat, and their pocket guides.
6. TheMarine Stewardship Council certifies fisheries that meet their standards for stainable harvests. Their label can be found on seafood in markets, especially in Europe. Click on their map to find certified fisheries.

Storm Surges

Great Storms Storms, especially hurricane and typhoons, also kill many people, do great damage to coastal structures, and erode the coast. Great storms in the middle ages removed tens of kilometers of Germany's coasts in a few years. A storm surge in the North Sea in 1953flooded most of the Netherlands and parts of eastern England, causing great damage and 2100 deaths. Hurricanes in the Gulf of Mexico move barrier islands, flood nearby land, and destroy coastal structures. "Thegreatest tropical system disaster this century occurred in Bangladesh in November 1970. Winds coupled with a storm surge killed between 300,000- 500,000 people." And the hurricane that struck Galveston Island on the evening and night of 8 September 1900 killed more than 6,000.

Left: Panorama of Galveston after hurricane hit the city on 8 September 1900. Right: Another view. From Texas State Archives andhttp://www.1900storm.com/and http://archives.cnn.com/2000/WEATHER/09/07/galvesto
. The Rosenberg Library in Galveston has many more photographs online.

Many other hurricanes have caused severe damage to the coast of the United States.

Storm Surges The damage results from waves riding on a rise of sea level, the storm surge. Many processes influence the height of the surge.

1. Wind speed. The force of the wind on the water is proportional to wind speed squared.
2. Wide shallow continental shelf offshore.The surge is directly proportional to the width of the shallow water, and inversely proportional to the depth. Essentially, hurricane force winds blowing onshore across tens of kilometers of shallow water pile up water along coast. The stronger the wind, the shallower the water, and the greater the extent of shallow water, the higher the pile of water. In some cases it can exceed 2-5 meters. In Galveston, Isaac Cline, the chief meteorologist, measured a rise of sea level greater than 16 feet above mean sea level.
3. Tides. If the surge occurs at high tide, the tide adds to the height of the surge.
4. Shape of the coast and winds at other areas along the coast. The surge can travel along the coast, causing high waters away from the strongest winds.
5. Barometric pressure. Sea level rises one centimeter per millibar drop is air pressure. Strong storms can have 50 millibar drop in pressure, causing a 50 cm rise in water levels on top of levels due to wind and tides.

All these factors are included in numerical forecasts of storm surge height produced by meteorological agencies such as the U.S. National Oceanic and Atmospheric Administration NOAA.

The NOAA Storm Surge Atlas for Florida shows how much of the land inland from the beach will be flooded by storms of various strengths. Other maps are available online. More information about storm surges is in the online textbook Introduction to Physical Oceanography under storm surges. NOAA has a web page that describes the different categories of storms according to the Saffir-Simpson Hurricane Scale.

To get a more graphic understanding of storm surges, look at these simulated storm surge pictures for Brunswick, GA, New Orleans, LA, Brooklyn, NY, Wrightsville Beach, NC and Manteo, NC, all from NOAA storm surge page. Here is asimulation of the storm surge (348 KBytes) generated by a hurricane approaching the Mississippi coast generated by the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) numerical forecasting model. Keep in mind, the pictures are misleading. There are always large storm waves on top of the surge, and the waves are missing from the photos. The make the surging water much more dangerous. They are large, and because they can pound coastal structures for hours, they can destroy buildings that might survive a tsunami having the same change in water level.

Mitigating Factors Storm surges are reduced by:

1. Offshore barrier islands and coral reef. Barrier islands are ”shock absorbers” absorbing storm surges. The shallow water slows the surge of water, reducing its amplitude at the mainland shore. Water travels at a velocity of roughly square root (gH), where g=gravity, and H=depth of water. In shallow areas above reefs H is small, and velocity is small.
2. Mangrove forests at the shore. The tangle of branches slows the flow of water.
3. Forests just inland of the beach. Many areas have, of had, extensive forests in the low flatlands just inshore of the beach that slow the velocity of water and reduce the height of waves and storm surge. Forests and mangrove areas also have many other uses: They are nurseries for fish, shrimp, crabs, and other valuable marine life; they provide wood and forest products; and they are a refuge for wildlife. In April 1991 a cyclone ravaged the Chittagong coastal belt [Bangladesh], located in the southern part of the country. But people of Mirsarai and Sitakunda, two coastal locations, suffered least

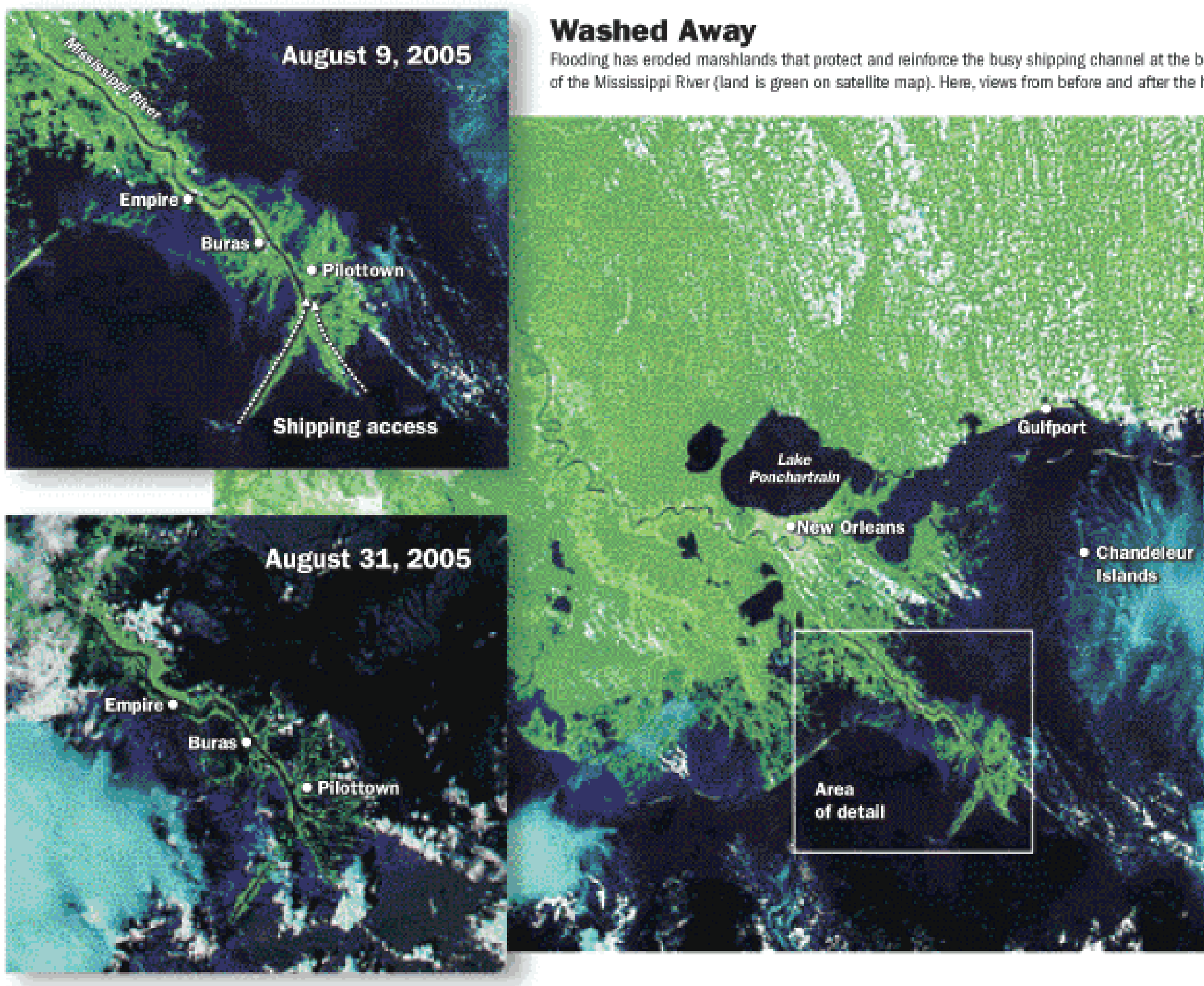
casualties and property damage in the cyclone primarily due to protection provided by a one-or-two kilometre wide belt of plantations along the shore. This proved the effectiveness of coastal plantations as protection against cyclone and storm surges. FromNatural Disasters, Forest and Environmental Security.

A view of Sundarban Mangrove forest of Bangladesh that has proven to be effective in reducing storm surges. From: http://www.ramsar.org/wn/w.n.bangladesh_sundarbans.htm

Lack of levees along rivers in coastal deltas. Flooding rivers deposit sediments in the lowlands of their their deltas, keeping the areas well above sea level.

Unfortunately, coastal development has removed many of these barriers.

1. Tsunami damage in Thailand in 2004 was much worse onshore of areas where coral reefs had been mined for rock.
2. Mangrove forests have been replaced by shrimp farms, and coastal forests have been replaced by houses, commercial buildings, streets, and highways.
3. The extensive system of levees along the Mississippi River has prevented the flooding of delta areas, forcing the river to deposit sediments in shallow offshore areas. As a result, the lowlands of the delta gradually sank below sea level. New Orleans, originally above sea level in the 19th century, was up to seven meters below sea level by the beginning of the 21st century. Hurricane Katrina's storm surge in August 2005 breached the levees protecting the city, leading to disastrous flooding and loss of life.
4. There is some evidence that the loss of coastal barriers made the hurricane Katrina storm surge worse, leading to the flooding of New Orleans in August 2005.



Extensive erosion of coastal lowlands of the Mississippi delta in August 2005 by the storm surge generated by hurricane Katrina. Image from *Wall Street Journal*, 2 September 2005, page B1.

Further Reading Isaac's Storm (1999) by Erik Larson, Crown Publishers, gives a thorough account of the Galveston hurricane of 1900, including first hand-accounts of those who survived a category 5 storm.

17.5 Coastal Erosion

Coastal erosion is a problem for those who live near coasts and for marine organisms living along the coast in bays, estuaries, and shallow waters. We have seen that beaches change with the seasons, and that tsunamis and storm surges can erode coasts. How important is coastal erosion? Are we making it better or worse? What causes erosion? Can it be prevented? Or do we want to allow erosion as a natural process?

> Many coastal areas are facing chronic long-term shoreline erosion problems. This is especially a problem along the low-lying barrier island systems of the Gulf and Atlantic coasts. Average erosion rates are 6 feet per year along the Gulf and 2 to 3 feet per year along the Atlantic. Some coastal areas may be accreting in the short term, but the general trend is in the direction of shoreline retreat. Beatley, Brower, and Schwab (2002).

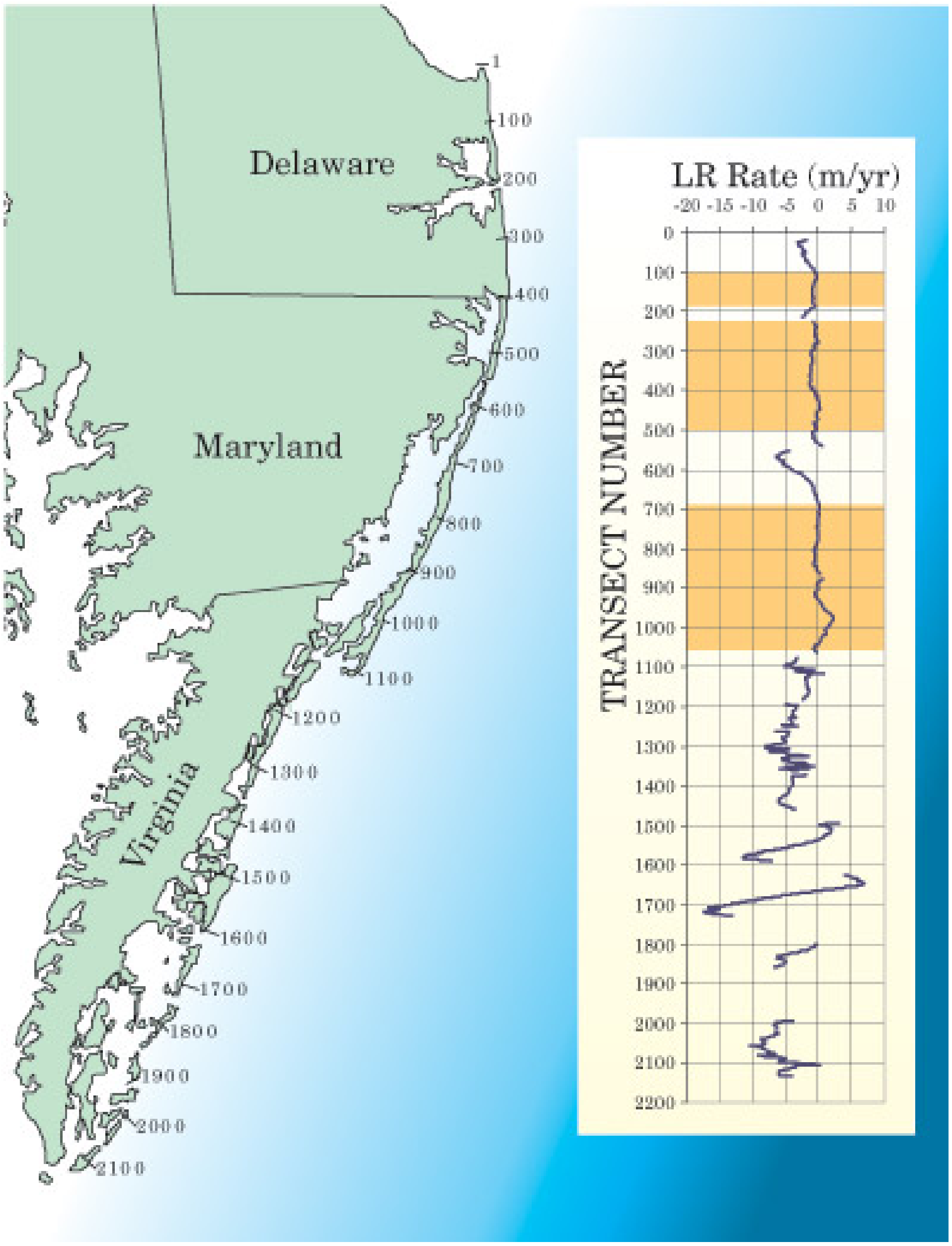
Coastal Erosion is Episodic and Sporadic

Read this Coastal Erosion Case Study of Cape Cod before class.

> The study has shown that the long term erosional rate for the bluffs in the area between the Pamet River and Beach Point averages less than 0.5 foot/year or less than 50 feet/century. Many residents and summer home owners develop a sense of security when property they have owned for decades has not eroded significantly. They are unprepared for sudden erosional events. However, when the bluffs do erode, they erode much more than 0.5 foot/year. The work of Uchupi and Giese suggests that the bluffs may erode 10-15 feet over a two to seven year period and then remain relatively stable for another 40-50 years.

Many other studies confirm this conclusion.

1. Beach erosion is episodic. Most erosion occurs over a short period, sometimes in hours during a hurricane such as Katrina, sometimes during a season as in California during an El Niño event.
2. Erosion is also sporadic. All areas are not eroded at the same rate during a storm. Some areas have severe erosion during an event. Other areas have mush less erosion.
   (a) Some areas are constantly and rapidly eroding. The Mississippi delta region in Louisiana is a major example. Some areas erode meters per year.
   (b) Other areas, such as the rocky west coast, erode at a rate of inches per year.



Erosion rates measured along the Delmarva coast. The location of the measurements shown in the inset is noted on the map on the left. Notice erosion rates are not uniform. Note also the large areas of deposition and erosion near locations 540 (Ocean City, see below), 1580, 1600, and 1700, all at chanels between barrier islands. From Day (2004).

Examples of Episodic and Sporadic Coastal Erosion

1. Erosion by Hurricane Rita
2. Coastal damage at Gulfport by Hurricane Katrina. Notice in photos houses just inland were not as damaged as beach houses.
3. Winter storm damage on the California coast
4. Erosion in the Florida wetlands
5. Erosion due to Hurricane Dennis.
6. Erosion due to Hurricane Andrew

7. Damage by Hurricane Jeanne
8. Damage by Hurricane Ivan
9. Teachers can find information at Coasts in Crisis

The Mississippi Delta is Rapidly Eroding

Deltas are normally slowly increasing in size due to sediment deposited by the river. The slow increase is due to a slight imbalance between sedimentation by the river, and sinking of the delta due to consolidation of deeper sediments. The balance has been upset by the construction of levees and dams along the Mississippi River leading to rapid erosion of the Mississippi River delta in Louisiana. It is the most rapidly eroding coast in the USA. Since 1900, about 4900 km^2 of wetlands in coastal Louisiana have been lost at rates as high as 100 km^2/year. The rate was 90 km^2/year for the 1978-90 time period.

The rapid erosion is due to several factors, the first two being the most important:

1. The construction of levees along the lower river that channel water and sediments past New Orleans and out into the Gulf. This has stopped sedimentation throughout the delta, and the delta is now rapidly sinking below sea level. If the levees did not exist the river channel carrying most of the river water would change position, and deposit sediments throughout the delta. With levees, land subsidence of 4 to 4.3 feet per century for the deltaic plain and 1.3 to 2 feet per century for the chenier plains in western Louisiana is not balanced by sediment from the river – from LaCoast maintained by the US Geological Survey.

Location of Mississippi River channels discharging water into the Gulf of Mexico over the past 5000 years. Notice the location changes from time to time, keeping the all areas of the delta supplied with sediments. Today, two-thirds of the flow are through the Bird Foot Delta (6) and one third through the Atchafalaya (1). From Day et al (2007).

The dredging of many canals to provide access to oil and gas wells. The canals help salt water reach further inland, resulting in death of trees and vegetation that stabilizes wetlands. Wind blowing along the canals produces waves that erode the banks. And, storm surges produced by storms travel along canals causing erosion further inland.

Table 17.25:

Canals dredged for navigation and hydrocarbon exploration in Louisiana. From USGS Fact Sheet on Louisiana Coastal Wetlands.

Wetlands and coastal features are composed mostly of silts and clays that are easily eroded.

Coastal features have little vertical relief.

Coastal Erosion is Aggravated by Man-Made Structures

To limit flooding, and to store water, governments build dams. To prevent loss of coastal land and buildings governments and property owners usually resort to building structures to hold back the sea and to prevent loss of sand. These structures do more harm than good over the long term.

1. Dams store sediments keeping them from nourishing and replenishing beaches. There are over 75,000 dams higher than six feet in height in the USA, and 1,971 in Texas. With little sand flowing to coastal areas, beaches are disappearing.
2. Coastal structures designed to limit erosion cause increased erosion in the long term.
    (a) Groins and other structures designed to limit sand transport along a beach, hold sand, and beaches down the beach are starved of sand. Erosion is great along these beaches.

Table 17.26:

Groins installed at Ocean City have impeded sand flow from left to right in this image, causing beaches to the left of the navigation channel to grow, and beaches to the right to erode away. From Google Maps.

(b) Seawalls designed to impede erosion lead to greater erosion. Sand in front of the wall gradually erodes away (that is why the wall was built), and eventually waves reach the wall. When they reflect off the wall, they create turbulence leading to faster erosion, undercutting the wall.
(c) Navigation channels cut through barrier islands disturb sediment transport along the island leading to erosion in some areas, and beach growth in other areas.
(d) Destruction of coastal vegetation, including mangroves, leads to faster erosion rates.

What to Do?

The problems seen in the film *Portrait of a Coast* are starkly highlighted at a coastal development on a Carolina coast, the Shell Island problem. Shell Island Resort is located on an offshore island, and an inlet at one end of the island is moving rapidly toward the resort. When it reaches the resort, the resort will be destroyed. The site outlines the problem, then provides background information on: What can be done? Should anything be done? Who should pay for any work?

Read whyengineering solutions do not work in the long run. Beach structures such as seawalls and groins provide short-term solutions, and long-term problems.

Coastal Erosion Policy Issues

People like to live close to the beach. Hundreds of thousands have bought homes on barrier islands or sandy stretches of coast. Not surprisingly, they hope to keep their property despite the relentless march of the sea into the land.

> When it comes to inhabiting the coast, there is no philosophical middle ground. People adapt one of the two positions exemplified by Mohn (a homeowner) and Pilkey (a scientist).: People are at the coast to stay, and Nothing along the coast stays forever. From Hiney (2004).

1. Should we retreat as the sea advances, allowing nature to maintain a balance? Until recently, few tried to hold back the sea.
2. Or should we reinforce the coast and stop the erosion?
3. In either case, who pays the cost of retreating or reinforcements.

Retreat or Reinforce the Coast?

Until recently, few tried to hold back the sea. Cities and towns were located a few miles inland away from the advancing sea. The few structures that were built at the beach tended to be simple, cheap, and easily abandoned.

Table 17.27:

Left: Simple beach house at Old Waikanae Beach, Wellington, New Zealand, typical of beach houses built 50 years ago. From Bookabach. Right: Beach houses in Shenzhen city, China. FromSteven's Personal Web Site.

As more and more people flocked to the coast, they began building expensive homes on dunes at the water's edge. Towns sprang up on barrier islands. Beachfront lots and property became very expensive.

Table 17.28:

	Suntide III

Condominium on South Padre Island, Texas, typical of modern beach construction. From SUNTIDE III CONDOMINIUMS.

17.6 Policy Questions

Should land be zoned to forbid building close to the water? Keeping people from building close to the beach is now highly controversial. Landowners have paid high prices for land in the expectation they could develop the land and make a profit. Rezoning greatly reduces the value of the land. But if zoning allows structures, they may be damaged by storms.

Should we allow reinforcement of the coast despite its long-term cost and environmental damage?

> Americans in great numbers are heading to beaches this summer to enjoy the sun, the surf, and the sand. But when they arrive, many are asking a common question: Where's the beach? Erosion, coastal over development, and misguided conservation efforts are taking a heavy toll on the nation's shoreline. For generations, the United States has been waging a multibillion-dollar war against the forces of wind and tide. But the wind and the waves are winning. The result: Coastal communities from Massachusetts to Texas to California are facing a shortage of sand. Their beaches are literally washing away. From Christian Science Monitor article At Beaches, Sand Is Running Out, 8 July 1999.

Sea-walls and other structures can protect a coast for a limited time. Eventually, sand is washed away from in front of the seawall, storm waves reach the wall, and eventually the wall fails. To prevent this from happening, sand must be periodically dumped on the beach at great cost. Eventually, some agencies are opting to stop replenishment and allowing natural processes to work. For example, in 2001 the U.S. Army Corps of Engineers abandoned a $52 Million project to add sand to the beach at Fire Island near New York.

> Signaling a change in public policy for Long Island's South Shore, the Army Corps of Engineers and New York State have agreed to abandon a $52 million project to construct oceanfront dunes and beaches along 11.3 miles of the most heavily developed areas of Fire Island ... greater consideration will be given to what is known as a nonstructural approach to shoreline management that emphasizes allowing nature to take its course and seeking to keep development out of harm's way. This approach is supported by state and national environmental organizations and is apparently gaining currency among government agencies. It would rule out so-called hardened structures like jetties and groins and would also stop or sharply limit dumping sand to build up dunes and widen beaches for storm protection.
>
> Proponents of nonstructural methods say that scientific evidence shows that dunes and beaches on barrier islands like the 31-mile-long Fire Island will restore themselves naturally if they are not impeded by oceanfront development or coastal engineering. They envision buying up land to create a "no development" buffer zone along the Atlantic. From New York Times article Corps Drops Sand-Replenishment Plan for Fire I, 15 April 2001.

Should we allow construction on coastal property subject to erosion or damage by storm surges and tsunamis? Remember the film *Portrait of a Coast* which began with footage showing a New England city that had been damaged by storms many times in the past century? The narrator stated that the cost of protection exceeded the cost of the buildings being protected. Is this good policy? Should areas damaged by the Indian Ocean tsunami be rebuilt? Or should the areas be turned into parks such as the park in central Hilo Hawaii?

> It was the 1960 tsunami that sparked legislation to establish a greenbelt in the hardest hit area of Hilo to prevent future losses of life and business. Dubbed Project Kaiko'o (Rough

Seas), tax benefits were granted to businesses and individuals to relocate. Part of the area was filled to a height of 30 feet, and when simulated waves over models of the area illustrated that the waves would no longer endanger that area, state buildings were erected there. Today, Wailoa State Park on the bayside of the state buildings, is a lovely, serene park with waterways shared by ducks and kayakers. Monuments have been erected at Lapahoʻehoʻe and at Wailoa State Park that serve as sad reminders of the 1946 and 1960 tsunamis. From http://www.coffeetimes.com/tsunamis.htm

Table 17.29:

The green areas in the center of this image of Hilo Hawaii, from the Wailuku River at top left to the Wailoa River on the right and center, were created after buildings in the area were destroyed by the 1946 and 1960 tsunamis. From Google Maps.

Who owns beach sand? Sand from rivers is essential for replenishing beaches. If the sand flow to the sea is blocked by dams, and if the sand is mined for construction projects, less sand is available for beaches. in essence, upstream users are taking the sand, depriving downstream users (beach owners). Should upstream users pay downstream users for the taking of sand?

Some Options

1. The individual property owner can assume liability. This is based on the presumption that the purchaser of coastal property knows the dangers, and therefore willingly accepts the liability by purchasing the property. Many states require the seller of the properly to disclose the dangers and liabilities.
2. Prohibit coastal structures through local zoning, and government ownership of land close to the beach. Many communities use zoning to prohibit the construction of structures in locations likely to be flooded. The concept can be extended to the coastal zone.
3. Mandatory hazard insurance. The local and federal government requires owners of structures in flood plains to obtain federal flood-plain insurance. The concept could be expanded to the coastal zone. If an area is repeatedly damaged, the insurer can take obtain ownership of the property and not rebuild.
4. The local or state government can assume liability. If coastal structures are damaged, the government will pay for repairs and/or seawalls and other structures necessary to protect the coastal structure. This has been common practice in some but not all regions. After insurance companies refused to insure Florida homes very likely to be damaged or destroyed by hurricanes, the state of Florida started a government-owned insurance program. Unfortunately, it does not have resources needed to repay homeowners whose homes are damaged by a major hurricane. So the state is asking the federal government to assume responsibility. In essence, all citizens in the country are asked to pay for damage to homes built in damage-prone areas of coastal Florida.
5. Require those who restrict the flow of beach sand to reimburse down-beach communities for the loss of sand. The California Coastal Commission requires fees be paid to build seawalls that keep sand from reaching southern California beaches. Read Report on In-Lieu Fee Beach Sand Mitigation Program: San Diego County

Federal Response to Coastal Erosion Problems

1. See US Department of Housing and Urban Development information on Special Flood Hazard Areas and regulations on building in these areas.
2. Executive Order 11988 – ”Floodplain Management” requires Federal agencies and Responsible Entities ”to avoid direct or indirect support to floodplain development wherever there is a practicable alternative.” The term ”floodplain” shall mean the lowland and relatively flat areas adjoining inland and coastal waters including flood prone areas of offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year. From Executive Order 11988
3. Federal Disaster Protection Act as amended authorized the ”National Flood Insurance Program” whose policy requires participating communities when issuing building permits to discourage but allow floodplain development on the condition that the construction be elevated and/or flood proofed and that the property owner obtain flood insurance protection against potential financial loss due to damage from flooding.
4. ”Executive Order 11990 - Protection of Wetlands” requires Federal agencies and Responsible Entities to avoid undertaking or providing financial assistance for new construction located within wetlands, unless a finding is made that there is no practicable alternative to such construction. Section 7 of the Executive Order defines the term ”wetlands” to mean ”those areas that are inundated by surface or ground water with a frequency sufficient to support and under normal circumstances do or would support a prevalence of vegetative or aquatic life that requires saturated or seasonally saturated soil

conditions for growth and reproduction. Wetlands generally include swamps, marshes, bogs, and similar areas such as sloughs, potholes, wet meadows, river overflows, mud flats, and natural ponds." The Fish and Wildlife Service of the Department of Interior also identifies most wetlands on the National Wetlands Inventory maps.

5. The Coastal Barrier Resources Act (1999) discourages development on coastal barriers, including barrier islands. It begins:
   (a) FINDINGS. – The Congress finds that–
      i. Coastal barriers along the Atlantic and Gulf coasts of the United States and the adjacent wetlands, marshes, estuaries, inlets and near shore waters provide–
         A. habitats for migratory birds and other wildlife; and
         B. habitats which are essential spawning, nursery, nesting, and feeding areas for commercially and recreationally important species of finfish and shellfish, as well as other aquatic organisms such as sea turtles;
      ii. Coastal barriers contain resources of extraordinary scenic, scientific, recreational, natural, historic, archeological, cultural, and economic importance; which are being irretrievably damaged and lost due to development on, among, and adjacent to, such barriers;
      iii. Coastal barriers serve as natural storm protective buffers and are generally unsuitable for development because they are vulnerable to hurricane and other storm damage and because natural shoreline recession and the movement of unstable sediments undermine manmade structures;
      iv. Certain actions and programs of the Federal Government have subsidized and permitted development on coastal barriers and the result has been the loss of barrier resources, threats to human life, health, and property, and the expenditure of millions of tax dollars each year; and
      v. A program of coordinated action by Federal, State, and local governments is critical to the more appropriate use and conservation of coastal barriers.
   (b) PURPOSE. – The Congress declares that it is the purpose of this Act to minimize the loss of human life, wasteful expenditure of Federal revenues, and the damage to fish, wildlife, and other natural resources associated with the coastal barriers along the Atlantic and Gulf coasts by restricting future Federal expenditures and financial assistance which have the effect of encouraging development of coastal barriers, by establishing a Coastal Barrier Resources System, and by considering the means and measures by which the long-term conservation of these fish, wildlife, and other natural resources may be achieved.
6. TheInsurance Information Institute provides information of catastrophic insurance, including flooding by hurricanes.

17.7 End of Chapter Review & Resources

Chapter Summary

Wetlands, greatly reduced because of earlier views that they were wasted land, provide many ecosystem services, including flood control, water purification, aquifer recharge, plant and wildlife habitat, and recreation. Coast regions are over developed and degraded, and this leads to erosion. Fish are over-fished and major declines in many economically important species is causing very serious concern. In one example, fishing was stopped and yet populations still have not come back after 10 years.

Review Questions

1. List the issues related to over fishing.
2. Outline the concerns by commercial fishing practices.
3. Understand the important ecosystem services provided by wetlands.

Further Reading / Supplemental Links

- The original article to Tragedy of the Commons in Science Magazine: http://www.sciencemag.org/content/162/3

Vocabulary to Know

- **wetlands**: swamps, marshes and bogs whose soil is saturated
- **coasts**
- **delta**
- **water pollution**
- **pollution**
- **commercial fisheries**

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Chapter 18

Environmental Economics & Law

18.1 Introduction

Humans require natural resources to survive, and those resources are based on ecosystem services. There are both renewable and non-renewable resources. Sustainably using energy sources allows both current and future generations the chance to a good life.

Chapter Objectives

- Understand key principles related to economics, cultures, and the environment.
- Outline what a cost-benefit analysis (CBA) is.
- Explain exploitation of companies in developing nations.
- Understand the concepts behind environmental justice and indigenous rights.
- Describe the role of policy and law in protecting the environment.
- Know some of the key players in environmental and cultural protection.

18.2 Economics & Prosperity

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

Capitalist countries such as the United States have a system that is largely based on a **pure market economy**. Buyers and sellers make economic decisions based on the **Principle of Supply and Demand**. Sellers supply goods and buyers create demand for goods.These two roles are often in conflict: buyers want to buy goods at low prices and sellers want to sell goods at high prices.

However, the two sides eventually compromise on a price at which buyers can find sellers willing to sell and sellers can find buyers willing to buy. This is known as the **market equilibrium price**. The equilibrium price can be considered as the intersection of the supply and demand curves.

Most countries strive to increase their capacities to produce goods and services and consider doing so as a positive sign of development. Economic growth is stimulated by population growth, which in turn increases the consumption of natural resources and increases the per capita consumption of goods and services. Various indicators are used to measure economic growth. One of them is the **Gross National Product (GNP)**, which represents the total market value of final goods and services produced by a country during a given period (usually one year).Unfortunately, GNP does not take into account the global nature of many companies.

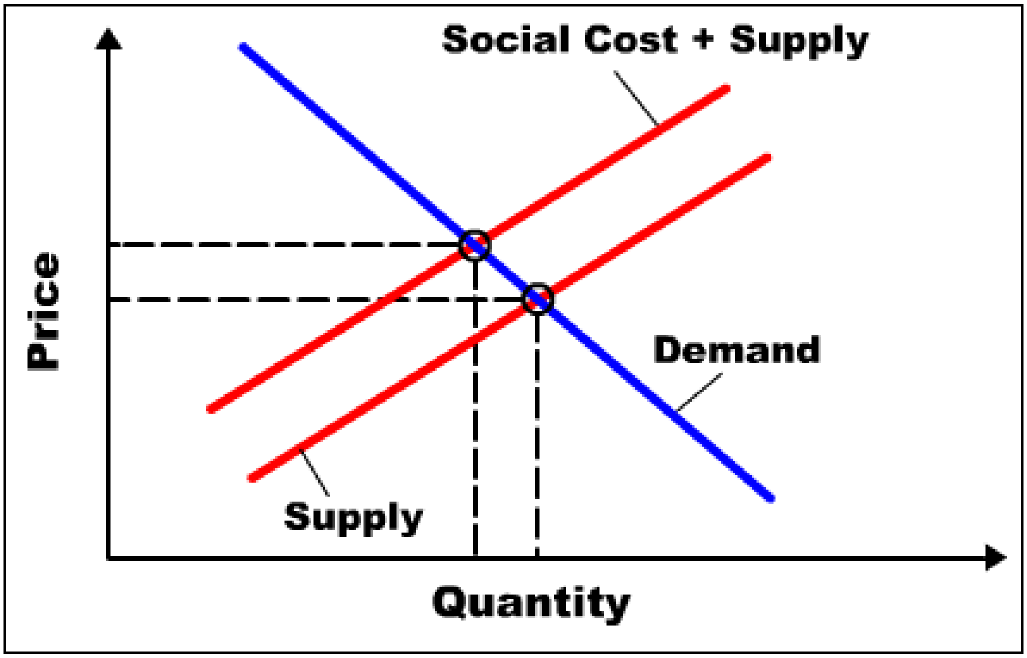
If a company produces goods in a foreign country, then the "home" country does not really benefit from that production. Thus, if Pepsi bottles and sells soda in Japan, those revenues should not be included in the GNP of the United States. The **GDP (Gross Domestic Product)** provides a better indicator of the health of a country's economy. This measure refers to the value of the goods and services produced within the boundaries of an economy during a given period of time.

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

External Costs

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

When external costs occur, a company's private production cost and the social cost of production are at odds. The firm does not consider the cost of pollution cleanup to be relevant, while society does. The social costs of production include the negative effects of pollution and the cost of treatment. As a result, the social costs end up exceeding the private production costs.



EXTERNAL COSTS

When external pollution and treatment costs are included in the production cost of the product, the supply curve intersects the demand curve at a higher price point. As a result of the higher price there will be less demand for the product and less pollution produced.

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

Sometimes, pollution results from the production process because no property rights are involved.

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

Firms have an incentive to use public goods in the production process because doing so does not cost anything. If the paper manufacturer can minimize production costs by dumping wastes for free into the local river then it will do so. The consequences of this pollution include adverse impacts on the fish and animal populations that depend on the water, degradation of the surrounding environment, decrease in the quality of water used in recreation and business, human health problems and the need for extensive treatment of drinking water by downstream communities.

An important role of the government is to protect public goods, especially those with multiple uses, from pollution by companies seeking to minimize company costs and to maximize profits. People desire clean water for recreation and drinking, and the government must act to protect the broad interests of society from the narrow profit-driven focus of companies.

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

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

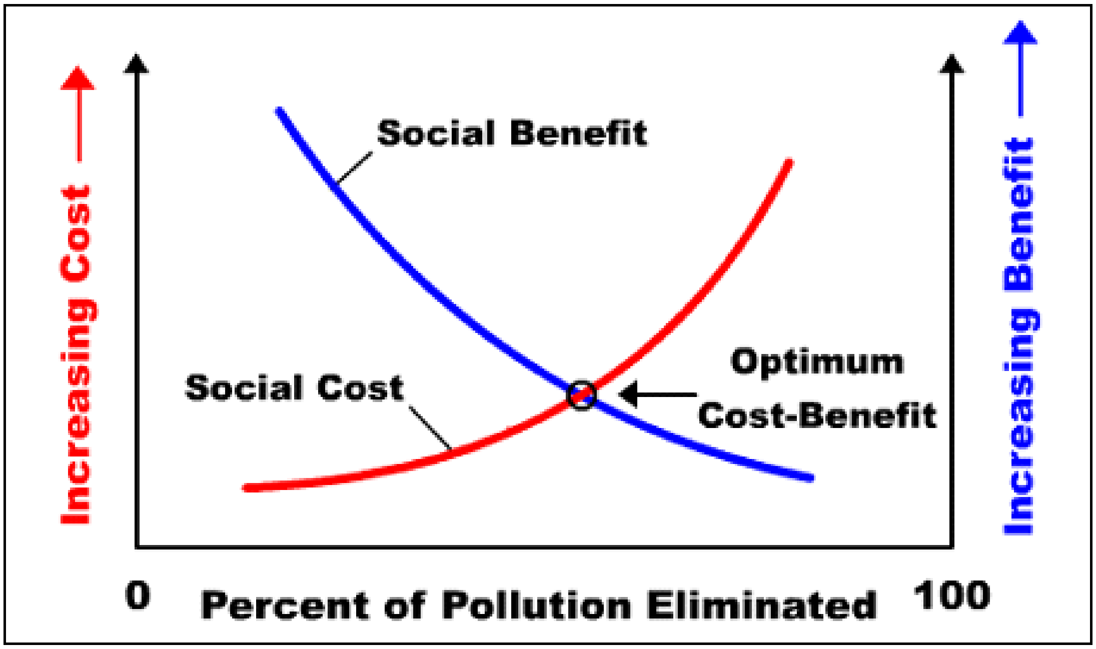
Tradable Pollution Permits (TPPs) are an alternative to pollution taxes.Â In 1994, the United States government inaugurated a program to reduce sulfur dioxide emissions by requiring that companies have a permit for each ton of sulfur dioxide they emit.Â Companies were allocated TPPs based on their historical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

See animation on External Costs: Click here.

Cost-Benefit Analysis

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

A **cost-benefit analysis** looks at the social benefits (e.g., health and environmental benefits) that can be derived from pollution reduction versus the cost of achieving that reduction.



COST BENEFIT

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

The optimum level is not static, but can change as circumstances change. As technology improves over time, the cost of pollution reduction may decrease.

Likewise, as the hazards of pollution become better known, the perceived benefits to be derived from pollution reduction may also increase. In either case, the optimum level of pollution reduction will then increase and a greater level of pollution reduction will be considered economically feasible. The eco-efficiency program at the 3M Corporation is an example of how the optimum level of pollution reduction can be raised through better management and design of manufacturing processes. Over the time period 1990 to 2000, the company reduced its air pollution by 88 percent, water pollution by 82 percent and waste generation by 35 percent.

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

See the animation on Cost-Benefit Analysis: Click here.

See the video on UCLA Co-Generation Facility: Click here.

18.3 Culture and Aesethics

The world's industrialized countries are undergoing many changes as they move to the later stages of the Industrial Revolution. Economies are becoming more information based, and capital is being measured not only in terms of tangible products and human workers, but also in terms of social and intellectual assets. For example, the makeup of the **Gross Domestic Product (GDP)** for the United States has gradually changed from being mainly manufactured goods to one with services predominating. Computer software and many other services, which are not easily categorized under the old economic system, now represent the largest sector of the United States' economy.

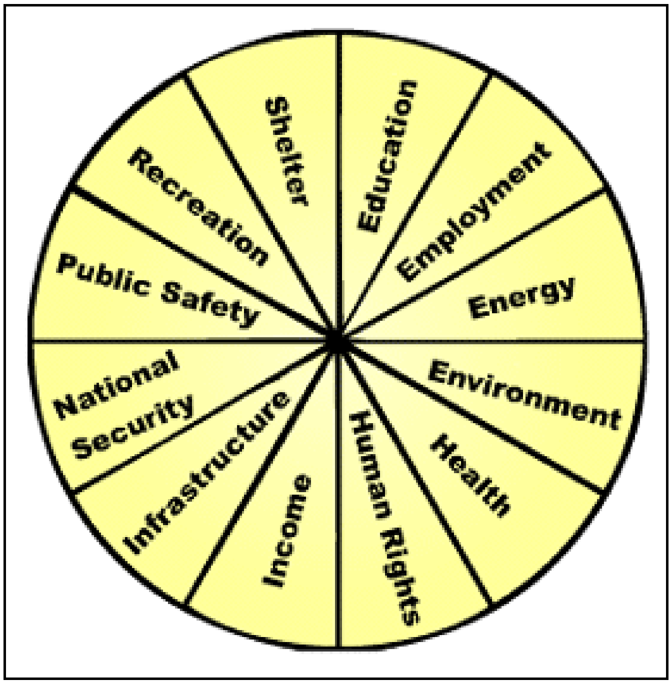
This change in economic thinking has brought about a deeper awareness of the natural processes and ecological assets found in nature. Society is slowly shifting to an industrial model that includes recycling. Such closed-loop production encompasses the principles of waste-reduction, re-manufacturing and re-use.

Conventional industrial economics considered air, water and the earth's natural cycles to be "free" goods. However, such thought led to considerable external environmental and social costs. With the rise of environmentally responsible economics, there is a movement to change to full-cost pricing of goods, which includes the social and environmental costs of production.

Attempts have been made to overhaul economic indicators such as the GDP to take into account intangible assets and intellectual property. In 1994, the Clinton Administration attempted to integrate environmental factors into the GDP. The World Bank in 1995 redefined its Wealth Index. A nation's wealth now consists of 60 percent human capital (social and intellectual assets), 20 percent environmental capital (natural assets), and 20 percent built capital (tangible assets). These **green GDP** figures are intended to provide a better measure of the quality of life in a country than the traditional GDP, which looked only at tangible economic factors.

However, such methods fail to take into account other areas that affect the quality of life in a country, such as human rights, health and education.

In attempts to develop a better measure of the quality of life of a region, separate sets of economic, environmental and social indicators have been devised. The reasoning of this is that it is better to consider several separate indicators, rather than try to create a single, catch-all index. This approach does not require the difficult, if not impossible, attempt to place monetary values on all factors. The Calvert-Henderson Group chose twelve separate quality of life indicators: education, employment, energy, environment, health, human rights, income, infrastructure, national security, public safety, recreation and shelter. Although separate, each indicator is related to the others, and all are based on readily available demographic data.



QUALITY OF LIFE INDICATORS

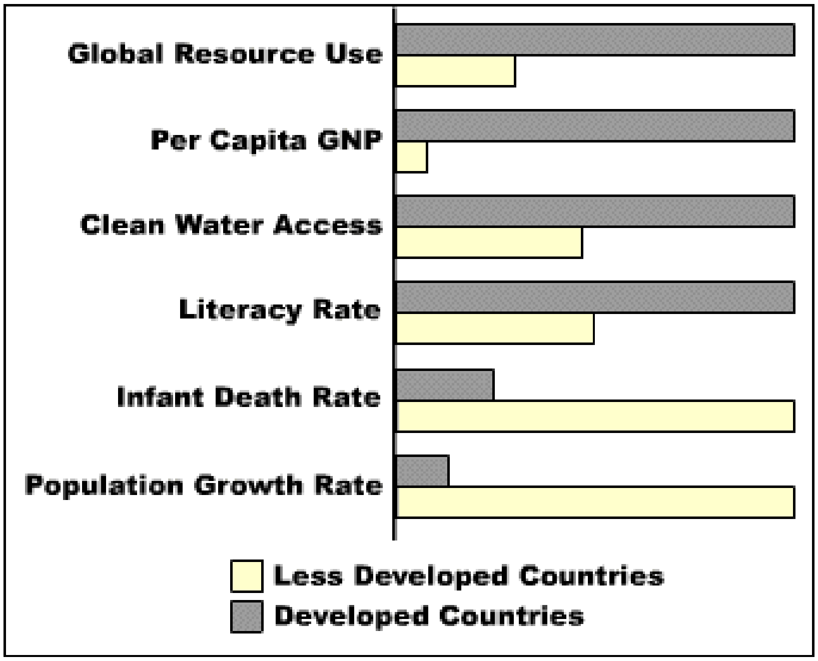
Categorizing Countries

Countries can be categorized by a variety of methods. During the Cold War period, the United States government categorized countries according to their government ideology and capitalist development. In this system, the "First World" included the capitalist countries; the "Second World" included the communist countries and the poorer countries were labeled as "Third World." With the end of the Cold War, this system has become archaic.

Current classification models utilize economic (and sometimes other factors), in their determination. One two-tiered classification system developed by the World Bank uses the categories of **developing country** and **developed country**. According to the World Bank classification, developing countries are those with low or middle levels of GNP per capita. More than 80 percent of the world's population lives in the more than 100 developing countries.

This is either because of the structure of their economies, or because their governments officially classify themselves as such. **Developed countries** are those that have a large stock of physical capital and in which most people have a high standard of living. Some economists consider middle-income countries as developed countries when they have transitional economies that are highly industrialized.

A three-tiered classification system was developed to categorize countries more precisely, especially those that are not easily classified as either developing or developed. These three categories are: **less developed country (LDC), moderately developed country (MDC)** and **highly developed country (HDC).** Criteria used to determine a country's category include: GNP per capita, transportation and communication facilities, energy consumption, literacy and unemployment.



DEVELOPED AND LESS DEVELOPED COUNTRY DICHOTOMY

A country categorized as an LDC has a marginal physical environment. Most African countries and many Asian countries are categorized as LDC. An LDC has the following characteristics: low energy production and consumption, mostly subsistence farming, a large percentage of the population is under 15, a high infant mortality rate, poorly developed trade and transportation inadequate medical facilities, a low literacy rate, a high unemployment rate and a very low per capita GNP.

Countries such as the United States, Japan, and most of the Western European countries are categorized as HDC. HDCs are characterized by: extensive trade, advanced internal communication systems, highly developed transportation networks, high energy production and consumption, advanced medical facilities, low population growth, political stability and a high per capita GNP. The MDCs have characteristics that fit into both the LDC and HDC categories, but have a moderate per capita GNP. Saudi Arabia, Brazil and Mexico are considered MDCs.

In a way, progress of less developed countries is determined somewhat, if not actively undermined, by the developed countries. Because developed countries are the more technologically advanced, they are able to maintain their advantage relative to less developed countries. One way they accomplish this is through "brain drain." With brain drain, the best educated people in less developed countries move to developed countries where they have better opportunities to improve their standard of living. Another way is for developed countries to exploit the natural and human resources of less developed countries. Developing countries generally desperately need the capital that developed countries can give them. Because environmental issues often take a backseat to economic issues, environmental disaster can follow.

An example of exploitation by a foreign corporation occurred in Bhopal, India.

Because of the availability of cheap labor and lax environmental laws, it was economically advantageous to locate a Union Carbide chemical plant there.

One day in 1984, a cloud of poisonous methyl isocyanate was accidentally released from the plant, killing most of the unprotected people in the adjacent areas. Houses near the plant were mostly of poor families and streets near the plant were populated with many homeless men, women and children. Several thousand people were killed in this disaster. Even after the settlement of lawsuits stemming from the accident, the injured and relatives of the dead received little compensation. Many of the homeless were completely ignored.

In its rush toward development, Bangladesh has established a program of intense use of land, forest, fisheries and water resources.

This has led to severe environmental degradation: loss of soil fertility, excessive extraction of groundwater for irrigation, and increased air and water pollution. The lowering of water tables throughout the land, in particular, has led to pollution of ground water by arsenic.

As many as 40 million people in Bangladesh may be exposed to toxic levels of arsenic present in many of the nation's six million private and public wells. The country does not have the economic resources for adequate testing of wells to determine which are poisoned and which are safe. Because of this, millions may die of cancer or "arsenicosis."

Some idealistic people believe that a definition of a developed country must include factors such as conservation and quality of life and that a truly developed country would not exploit a large fraction of the world's resources.

Accordingly, characteristics of such a developed country might include: economic prosperity of all people, regardless of gender or age, sustainable use of resources and more controlled use of technology to ensure a high quality of life for all people. An economically and technologically developed country such as the United States would not qualify as being a truly developed country by these criteria.

18.4 Environmental Justice

Whenever a community is faced with the potential of an environmentally undesirable facility, such as the placement of a hazardous waste dump in its midst, the usual response from residents is: "Not in my back yard!" Such a response is known as the NIMBY principle. Such reactions are usually reactions to visions of previous environmental irresponsibility: uncontrolled dumping of noxious industrial wastes and rusty steel drums oozing hazardous chemicals into the environment. Such occurrences were all too real in the past and some are still taking place. It is now possible – and much more common – to build environmentally sound, state-of-the-art disposal facilities. However, the NIMBY principle usually prevents the construction of such new facilities. Instead, hazardous waste facilities tend to be built upon pre-existing, already contaminated sites, even though the geology of such locations may be less favorable for containment than potential new sites.

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 years of rampant pollution and hazardous waste dumping.

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 peoples **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 Eskimos 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: 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.

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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.

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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.

See the animation about Project Chariot : click here.

See the video about Indigenous People: The Chumash in California

18.5 Environmental Laws and Regulations

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

Significant environmental action began at the beginning of the 20th century. In 1906, Congress passed the "Antiquities Act," which authorizes the president to protect areas of federal lands as national monuments. A few years later, **Alice Hamilton** pushed for government regulations concerning toxic industrial chemicals. She fought, unsuccessfully, to ban the use of lead in gasoline.

She also supported the legal actions taken by women who were dying of cancer from their exposure to the radium then used in glow-in-the-dark watch dials. During the early 1960's, biologist **Rachel Carson** pointed out the need to regulate pesticides such as DDT to protect the health of wildlife and humans.

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

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

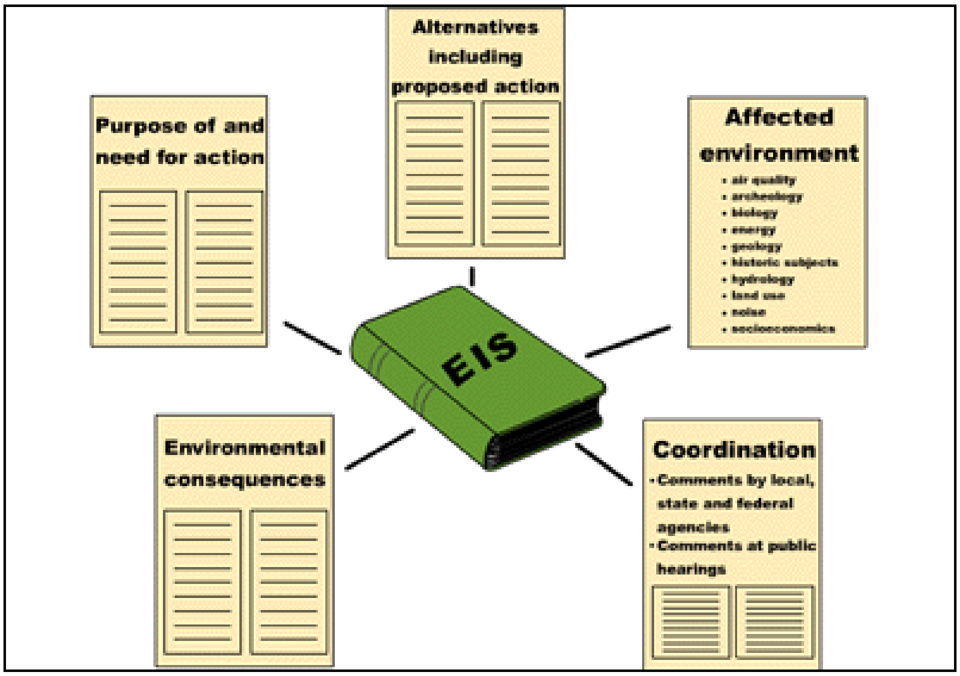

See the video about Environmental Laws and Regulations: Click here.

Federal Laws: USA

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

Many consider NEPA to be the most far-reaching environmental legislation ever passed by Congress. The basic purpose of NEPA is to force governmental agencies to comprehensively consider the effects of their decisions on the environment. This is effected by requiring agencies to prepare detailed **Environmental Impact Statements** (EIS) for proposed projects. The EPA is the government's environmental watchdog.

It is charged with monitoring and analyzing the state of the environment, conducting research, and working closely with state and local governments to devise pollution control policies. The EPA is also empowered to enforce those environmental policies. Unfortunately, the agency is sometimes caught up in conflicts between the public wanting more regulation for environmental reasons and businesses wanting less regulation for economic reasons. Consequently, the development of a new regulation can take many years.



ENVIRONMENTAL IMPACT STATEMENT

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

- The **Federal Clean Air Act** (1970, 1977 & 1990) established national standards for regulating the emission of pollutants from stationary and mobile sources.
- The **Federal Water Pollution Control Act** (1972) amended by the **Clean Water Act** (1977, 1987), established water quality standards; provides for the regulation of the discharge of pollutants into navigable waters and for the protection of wetlands.
- The **Federal Safe Drinking Water Act** (1974, 1977 & 1986) set drinking water standards for levels of pollutants; authorizing the regulation of the discharge of pollutants into underground drinking water sources.
- The **Toxic Substances Control Act** (1976) provided for the regulation of chemical substances by the EPA and the safety testing of new chemicals.
- The **Resource Conservation and Recovery Act** (1976) established cradle-to-grave regulations for the handling of hazardous wastes.
- The **Comprehensive Environmental Response, Compensation and Liability Act** (1980), also known as the **Superfund** program, provided for the cleanup of the worst toxic waste sites.

- The **Food Security Act** (1985, 1990) later amended by the **Federal Agriculture Improvement and Reform Act** (1996), discouraged cultivation of environmentally sensitive lands, especially wetlands, and authorized incentives for farmers to withdraw highly erodible lands from production.

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

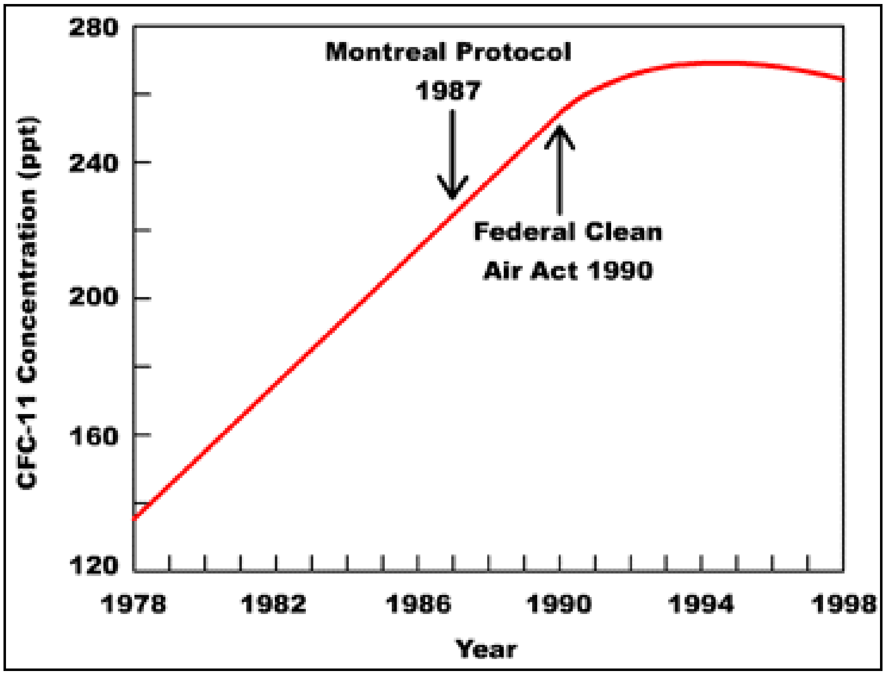

See the animation about the Super Fund: Click here.

International Treaties and Conventions

Conventions, or treaties, generally set forth international environmental regulations. These conventions and treaties often result from efforts by international organizations such as the **United Nations (UN)** or the**World Bank**. However, it is often difficult, if not impossible, to enforce these regulations because of the sovereign rights of countries. In addition rules and regulations set forth in such agreements may be no more than non-binding recommendations, and often countries are exempted from regulations due to economic or cultural reasons. Despite these shortcomings, the international community has achieved some success via its environmental agreements. These include an international convention that placed a moratorium on whaling (1986) and a treaty that banned the ocean dumping of wastes (1991).

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

- **The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.** As a result of this global agreement, industrialized countries have ceased or reduced the production and consumption of ozone-depleting substances such as chlorofluorocarbons.
- **The Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade**. This agreement enhances the world's technical knowledge and expertise on hazardous chemicals management.



CFC CONCENTRATION IN THE ATMOSPHERE

- **The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).** This agreement protects over 30,000 of the world's endangered species.
- In 1995 **UNEP and the International Olympic Committee (IOC)** signed a partnership agreement to develop environmental guidelines for sports federations and countries bidding to host the Olympic games.
- **The Rotterdam Convention** (1998) addressed the growing trade in hazardous pesticides and chemicals. Importing countries must now give explicit informed consent before hazardous chemicals can cross their borders.
- **The International Declaration on Cleaner Production** (1998). The signatories commit their countries to implement cleaner industrial production and subsequent monitoring efforts.

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

See the animation about the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES): click here.

18.6 End of Chapter Review & Resources

Chapter Summary

GDP does not always include all the external costs to the environment, cultures, and people. Some items included in the GDP of some countries could even be counter to prosperity as a nation might prefer, such as child trafficking and prostitution. Through a CBA stakeholders can try to logically evaluate all the input and output costs of different actions and projects. Quality of life is about more than the amount of money a nation makes. There are many indicators that economists feel have been loeft out of GDP calculations and many now prefer to use the United Nation's Human Development Index (HDI), which looks at a wider variety of factors related to national well being. Often business practices over exploit the cultures, people, and natural resources of other nations. National laws and policies are meant to help protect people's rights.

Review Questions

1. What does HDI stand for, and what does it mean?
2. How are external costs to the environment and cultures not included in current business practices?
3. In what ways is GDP an insufficient measure of national prosperity?
4. What is a CBA and how does one perform it?
5. Who are key players in the environmental and cultural protection arenas?

Further Reading / Supplemental Links

- The original article to Tragedy of the Commons in Science Magazine: http://www.sciencemag.org/content/162/3

Vocabulary to Know

- **Economics**
- **Natural resources**
- **human resources**
- **pure command economy**
- **pure market economy**
- **Principle of Supply and Demand**
- **market equilibrium price**
- **Gross National Product (GNP)**,
- **GDP (Gross Domestic Product)**
- **United Nations Human Development Index**
- **Tradable Pollution Permits (TPPs)**
- **cost-benefit analysis**
- **developing country**
- **developed country**
- **less developed country (LDC),**
- **moderately developed country (MDC)**
- **highly developed country (HDC)**
- **indigenous**
- **Environmental Impact Statements** (EIS)

Chapter 19

Sustainable Development

19.1 Introduction

This chapter takes a brief look at sustainable development, cultures, and environmental education.

Chapter Objectives

- Understand the connection between cultures, economy and the environment.
- Look at indicators of quality life that focus on more than just GDP (Gross Domestic Product).
- Understand the negatives affects of unsustainable resource use on indigenous groups around the world.
- Describe what sustainable development is.

19.2 Culture and Aesethics

The world's industrialized countries are undergoing many changes as they move to the later stages of the Industrial Revolution. Economies are becoming more information based, and capital is being measured not only in terms of tangible products and human workers, but also in terms of social and intellectual assets. For example, the makeup of the **Gross Domestic Product (GDP)** for the United States has gradually changed from being mainly manufactured goods to one with services predominating. Computer software and many other services, which are not easily categorized under the old economic system, now represent the largest sector of the United States' economy.

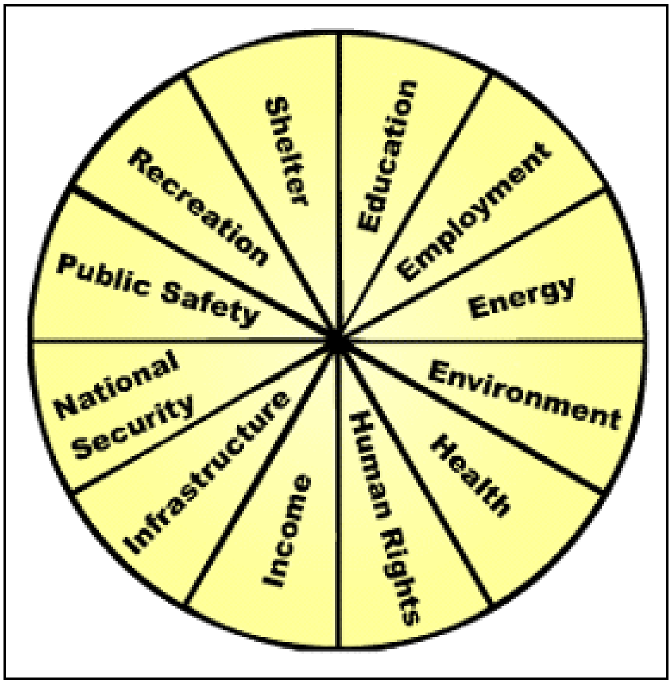
This change in economic thinking has brought about a deeper awareness of the natural processes and ecological assets found in nature. Society is slowly shifting to an industrial model that includes recycling. Such closed-loop production encompasses the principles of waste-reduction, re-manufacturing and re-use.

Conventional industrial economics considered air, water and the earth's natural cycles to be "free" goods. However, such thought led to considerable external environmental and social costs. With the rise of environmentally responsible economics, there is a movement to change to full-cost pricing of goods, which includes the social and environmental costs of production.

Attempts have been made to overhaul economic indicators such as the GDP to take into account intangible assets and intellectual property. In 1994, the Clinton Administration attempted to integrate environmental factors into the GDP. The World Bank in 1995 redefined its Wealth Index. A nation's wealth now consists of 60 percent human capital (social and intellectual assets), 20 percent environmental capital (natural assets), and 20 percent built capital (tangible assets). These **green GDP** figures are intended to provide a better measure of the quality of life in a country than the traditional GDP, which looked only at tangible economic factors.

However, such methods fail to take into account other areas that affect the quality of life in a country, such as human rights, health and education.

In attempts to develop a better measure of the quality of life of a region, separate sets of economic, environmental and social indicators have been devised. The reasoning of this is that it is better to consider several separate indicators, rather than try to create a single, catch-all index. This approach does not require the difficult, if not impossible, attempt to place monetary values on all factors. The Calvert-Henderson Group chose twelve separate quality of life indicators: education, employment, energy, environment, health, human rights, income, infrastructure, national security, public safety, recreation and shelter. Although separate, each indicator is related to the others, and all are based on readily available demographic data.



QUALITY OF LIFE INDICATORS

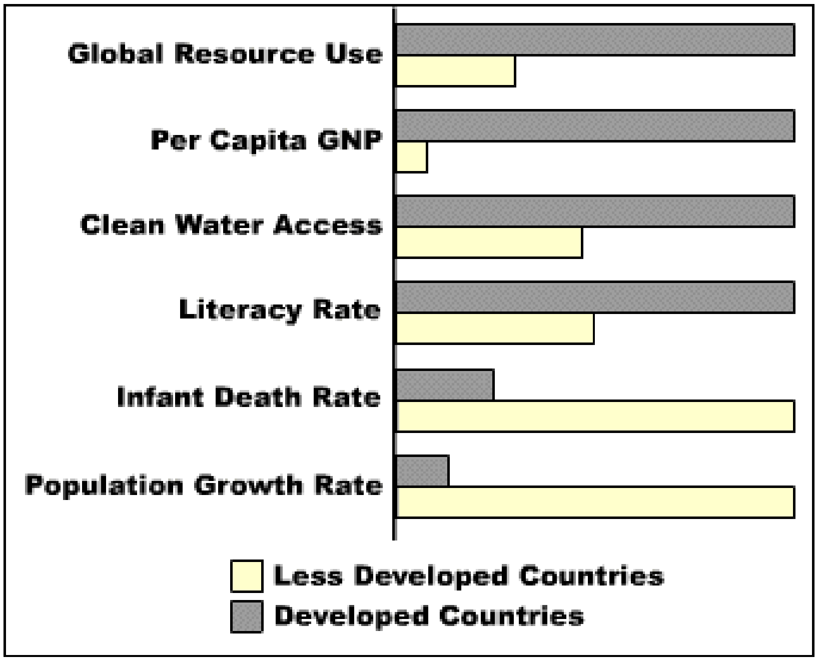
Categorizing Countries

Countries can be categorized by a variety of methods. During the Cold War period, the United States government categorized countries according to their government ideology and capitalist development. In this system, the "First World" included the capitalist countries; the "Second World" included the communist countries and the poorer countries were labeled as "Third World." With the end of the Cold War, this system has become archaic.

Current classification models utilize economic (and sometimes other factors), in their determination. One two-tiered classification system developed by the World Bank uses the categories of **developing country** and **developed country**. According to the World Bank classification, developing countries are those with low or middle levels of GNP per capita. More than 80 percent of the world's population lives in the more than 100 developing countries.

This is either because of the structure of their economies, or because their governments officially classify themselves as such. **Developed countries** are those that have a large stock of physical capital and in which most people have a high standard of living. Some economists consider middle-income countries as developed countries when they have transitional economies that are highly industrialized.

A three-tiered classification system was developed to categorize countries more precisely, especially those that are not easily classified as either developing or developed. These three categories are: **less developed country (LDC), moderately developed country (MDC)** and **highly developed country (HDC).** Criteria used to determine a country's category include: GNP per capita, transportation and communication facilities, energy consumption, literacy and unemployment.



DEVELOPED AND LESS DEVELOPED
COUNTRY DICHOTOMY

A country categorized as an LDC has a marginal physical environment. Most African countries and many Asian countries are categorized as LDC. An LDC has the following characteristics: low energy production and consumption, mostly subsistence farming, a large percentage of the population is under 15, a high infant mortality rate, poorly developed trade and transportation inadequate medical facilities, a low literacy rate, a high unemployment rate and a very low per capita GNP.

Countries such as the United States, Japan, and most of the Western European countries are categorized as HDC. HDCs are characterized by: extensive trade, advanced internal communication systems, highly developed transportation networks, high energy production and consumption, advanced medical facilities, low population growth, political stability and a high per capita GNP. The MDCs have characteristics that fit into both the LDC and HDC categories, but have a moderate per capita GNP. Saudi Arabia, Brazil and Mexico are considered MDCs.

In a way, progress of less developed countries is determined somewhat, if not actively undermined, by the developed countries. Because developed countries are the more technologically advanced, they are able to maintain their advantage relative to less developed countries. One way they accomplish this is through "brain drain." With brain drain, the best educated people in less developed countries move to developed countries where they have better opportunities to improve their standard of living. Another way is for developed countries to exploit the natural and human resources of less developed countries. Developing countries generally desperately need the capital that developed countries can give them. Because environmental issues often take a backseat to economic issues, environmental disaster can follow.

An example of exploitation by a foreign corporation occurred in Bhopal, India.

Because of the availability of cheap labor and lax environmental laws, it was economically advantageous to locate a Union Carbide chemical plant there.

One day in 1984, a cloud of poisonous methyl isocyanate was accidentally released from the plant, killing most of the unprotected people in the adjacent areas. Houses near the plant were mostly of poor families and streets near the plant were populated with many homeless men, women and children. Several thousand people were killed in this disaster. Even after the settlement of lawsuits stemming from the accident, the injured and relatives of the dead received little compensation. Many of the homeless were completely ignored.

In its rush toward development, Bangladesh has established a program of intense use of land, forest, fisheries and water resources.

This has led to severe environmental degradation: loss of soil fertility, excessive extraction of groundwater for irrigation, and increased air and water pollution. The lowering of water tables throughout the land, in particular, has led to pollution of ground water by arsenic.

As many as 40 million people in Bangladesh may be exposed to toxic levels of arsenic present in many of the nation's six million private and public wells. The country does not have the economic resources for adequate testing of wells to determine which are poisoned and which are safe. Because of this, millions may die of cancer or "arsenicosis."

Some idealistic people believe that a definition of a developed country must include factors such as conservation and quality of life and that a truly developed country would not exploit a large fraction of the world's resources.

Accordingly, characteristics of such a developed country might include: economic prosperity of all people, regardless of gender or age, sustainable use of resources and more controlled use of technology to ensure a high quality of life for all people. An economically and technologically developed country such as the United States would not qualify as being a truly developed country by these criteria.

19.3 Environmental Justice

Whenever a community is faced with the potential of an environmentally undesirable facility, such as the placement of a hazardous waste dump in its midst, the usual response from residents is: ”Not in my back yard!” Such a response is known as the NIMBY principle. Such reactions are usually reactions to visions of previous environmental irresponsibility: uncontrolled dumping of noxious industrial wastes and rusty steel drums oozing hazardous chemicals into the environment. Such occurrences were all too real in the past and some are still taking place. It is now possible – and much more common – to build environmentally sound, state-of-the-art disposal facilities. However, the NIMBY principle usually prevents the construction of such new facilities. Instead, hazardous waste facilities tend to be built upon pre-existing, already contaminated sites, even though the geology of such locations may be less favorable for containment than potential new sites.

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See the animation about Project Chariot : click here.

See the video about Indigenous People: The Chumash in California

19.4 Sustainability

19.5 End of Chapter Review & Resources

Chapter Summary

Moving economies, governments, and natural resource use closer to sustainable practices will help protect natural ecosystems and biodiversity while at the same time recognizing the human need for a good life.

Review Questions

1. Define sustainability.
2. What is environmental justice?
3. How are indigenous groups most affected by environmental degradation?
4. How can sustainable development initiatives help protect cultures, economies and nature at the same time?

Vocabulary to Know

toxic colonialismindigenoussustainable developmentenvironmental educationenvironmental justice

Chapter 20

Strategy to Review: Conservation Management

20.1 Scale of action

Biological conservation management applies ecological **evidence** and practical **experience** to formulate and implement actions to maintain or attain a specific **ecological objective**, which is agreed upon by consensus and/or prescribed by legislation.

On a global scale the concept of Earth being a **single system** is easy to comprehend. The material resources are **finite**, and significant amounts of matter are neither lost nor gained across the boundary between atmosphere and space. Our planet is essentially a closed system with respect to matter but an open one so far as energy is concerned (Phillipson 1975). Radiant energy from the sun enters the biosphere and is re-radiated to space as heat. The maintenance of global stability requires that the biospheric inputs and outputs of energy equal each other over time; if this equality is severely disrupted then unstable conditions will persist until the changed amounts of input and output equalize and a new equilibrium is achieved.

Global warming is a clear indication of unstable, non-equilibrium conditions. A new equilibrium will eventually be reached but the question is whether, when it is reached, will conditions be suitable for human existence and well being.

The **biosphere** provides the scale on which global conservation strategies and management operations function. The natural resources of the biosphere are, in effect, assets; as such they can be categorized as either fixed or current. The fixed assets are the non-living (abiotic) components, exemplified by gases (the atmosphere), water bodies (the hydrosphere), and solid inorganic matter (the lithosphere); together these constitute the physico-chemical environment. The current assets are the living (biotic) components—a potentially renewable stock of plants (flora) and animals (fauna). Transfers within and between the two major types of asset can, and do, take place; for example, the daily exchanges of heat energy between atmosphere, hydrosphere, and lithosphere and also the biological processes of photosynthesis and decomposition which involve energy transformations and exchange of chemical elements between abiotic and biotic parts of the biosphere.

The virtually closed biosphere is clearly a mosaic of many interacting smaller systems in which the sum of the parts is more stable than any one of the constituent parts. Biospheric stability and local ecosystem stabilities are inextricably linked; on these grounds alone a strong case can be made for protecting the Earth's natural ability to regulate its own stability by maintaining habitat diversity. Management of the biosphere's present habitat diversity and natural resources is multinational. In 1973 it was estimated that 174 nations each had a share of global assets, which included 1841 thousand million metric tonnes dry mass of plant material (Phillipson 1973).

On a smaller local or regional scale every ecosystem—be it on land or in the ocean—is, like the biosphere, a functioning system. Unlike the biosphere, however, significant amounts of matter can be lost or gained across boundaries (which are frequently difficult to define). Ecosystems smaller than the biosphere are essentially **open systems**with respect to matter as well as energy. Left unperturbed over ecological or evolutionary time the constituent ecosystems of the biosphere will, as a result of interactions between organisms and environment, also reach a state of equilibrium; classical examples of this are mature tropical forests and well-established coral reefs. Because of the dynamic nature of the interactions between living and non-living components, ecosystems smaller than the biosphere rarely achieve a fixed and lasting equilibrium, and instead exhibit varying degrees of fluctuation (Phillipson 1989a).

Commitment to conservation, including sustainable development objectives, appears to be strongest when:

- an influential leader declares it should be so;
- non-government agencies actively promote conservation;
- local people become involved in conservation projects;
- local people benefit either financially or in kind as a result of conservation activities;
- the country itself makes a substantial contribution in cash or kind to conservation.

20.2 Systems thinking

Ecological thinking is about studying organisms in space and time, classifying patterns of distribution and describing the response of populations to physical/biological factors and the impact of human exploitation. This basic ecological knowledge is **applied** to make conservation management plans in order to predict the consequences of a particular action in a conservation management system.

A conservation management system is based on evidence about:

- boundaries (e.g. the study of species area relationships)
- distributions of species (e.g. the study of effects of local variations in light)
- classification of communities (e.g. vegetation analysis)
- inputs and flows of energy (e.g. analysis of food chains)
- inputs and cycling of nutrients (e.g. measurement of nutrient reservoirs)
- behaviour of populations in response to: -
  - physical factors such as climate, geography and soils;
  - biological factors such as disease and predation;
  - human factors connected with the use of land and water; such as pollution;
  - the exploitative management of species and habitats; such as hunting.
  - experience from management systems for the same species in similar habitats

Conservation management implies the control of environmental and socioeconomic factors in order:

- to make more efficient use of materials,
- to recycle materials and energy that are vital to human survival,
- to restore derelict land
- and to maintain the capacity of ecosystems, which are the basis of all economies, to renew and grow.

This is a vast area of applied science and technology, which is developing alongside new social organisations that are changing cultural attitudes towards the value of natural resources.

Over the years, particularly at a governmental level, conservation management has come to focus on biological resources such as:

- Agriculture and pastoralism
- Fisheries
- Forest ecosystems
- Water
- Tourism and recreation
- Wildlife
- Genetic resources

From this perspective the aim is to foster attitudes in community and industry to the use of biological resources, changing from the 'maximum yield' approach to one of ecologically sustainable yield. This new attitude recognises the need for conservation of biodiversity and maintenance of ecological integrity.

20.3 Strategies and operations

Since the first Earth Summit in 1992, national strategies are now commonly in place to integrate conservation management within and between industries and communities to meet appropriate environmental, economic and social objectives. The practical aim is now to turn these strategies into operational systems and so balance exploitative management of natural resources with their conservation management. The goal is to provide the principles and tools to soften the clash between Earth's ability to sustain life and the character of its human occupancy. This means developing methods for biological conservation management alongside softer technological organisations for production (natural economy) and 'green' legislative actions for the organisation of people for production (political economy).

The global educational topic-framework, which links conservation management with exploitative management, has been defined as 'cultural ecology'. It is within this area of knowledge that conservation management systems can be seen to require more than the scientific input of conservation biology. The essential feature of conservation management programmes is that they are part of the linkages between environmental, social and economic progress; between peace and security; between productivity of environment and community; and between sustainability and the renewal and extension of democracy. In this sense, conservation management is about working on behalf of ecosystems to restore a culture where people are engaged with their place on the planet for the long term future.

It is commonplace to hear conservation managers stress that they are really naturalists who do their best to apply good science to ecosystems that are unique in each case history. No two sites share the same history and factors limiting their biodiversity. They will differ with respect to time lags and non-linear responses to a given intervention. From this point of view conservation systems have much in common with the management systems of farmers and gardeners with regards uncertainties of the effects of inputs. Because of the internal complexity of ecosystems, science has yet to answer fundamental question that were posed by Darwin regarding the factors that control relative abundance of species, with respect to space, time, pattern, food chains and population dynamics. There are fundamental questions in ecological science that underpin all conservation management systems.

Every nature reserve is likely to have some or all of the following questions unanswered:

- How do organisms change with space?

- How do organisms change with time?
- How do organisms exist in patterns?
- How do organisms exist in food chains?
- How do organisms exist in populations?

Answers to these questions are embedded in the conservation management system. All environmental systems are **open systems** with throughputs of matter and energy whilst maintaining structure and permanence in the medium term. A conservation management system will become part of this ecosystem with linkages to several feedback mechanisms, some positive and some negative, so that feedback loops can be unpredictable. This situation makes it virtually impossible to map the system as a whole, and usually the feedback is only revealed as an unexpected response, once management has commenced. It is in this sense that a management plan can be considered as the first stage of a research project, and the plan is adapted in response to its outcomes.

The aim of this chapter is to exemplify the application of the above five pillars of ecology to conservation management systems.

20.4 Conservation management systems

A conservation management system is a procedure for maintaining a species or habitat in a particular state. It is a means whereby humankind secures wildlife in a favourable condition for contemplation, education or research, in perpetuity. It is an important topic in cultural ecology, where conservation management counterbalances the unchecked exploitative management of natural resources. Conservation management systems are vital for turning sustainable development strategies into successful operations.

The UK experience

As a British idea the concept of a national conservation management system may be traced to an upsurge of sentiment after the Second World War that the world should be made a better place. It was the botanist Arthur Tansley who pleaded for organised nature conservation on the double ground of scientific value and beauty. He had advanced the concept of the ecosystem in 1935, and a number of key ideas of relevance to nature conservation stem from this. In the immediate post-war years, he hoped for an 'Ecological Research Council', and a 'National Wildlife Service'. In this context, the idea of national standards of conservation management can be traced to the formation of the Nature Conservancy Council (NCC), and its great survey of habitats and species, the Nature Conservation Review, published in 1977. From this time there was general agreement that the common purpose of conservation management systems was to transform situations of ecological confrontation between humans and non-humans into a system of mutual accommodation. The NCC's first guidelines for managing its national resource was a pro forma to accommodate a description of the site, the goals of management, and a prescriptive section, in which the objectives of management were to be interpreted in a practical manner. Central to the latter section were lists of codified jobs to help wardens abide by best practice. The major shortcoming of the guidelines was the lack of a business philosophy to track value for the inputs of effort and resources.

Britain's first proper conservation management system (CMS), which tied objectives to practical interventions with feedback from monitoring outcomes, coalesced around Mike Alexander (Warden of Skomer Island National Nature Reserve), Tim Read (staff member of the Joint Nature Conservation Committee) and James Perrins (an environmental/IT graduate of York University). This initiative in the 1980s led to the setting up of the CMS Partnership by the UK's main conservation agencies, which produced a relational database for linking management objectives with scheduled on-site operational inputs. The database recorded all actions, particularly the results of monitoring against performance indicators. Over the years the software has improved greatly with respect to the user/screen interface, but the data model is still very much the same as in the original programme, which was produced with 'Advanced Revelation'. Although the NCC has been replaced by four country agencies, in terms of the widespread uptake of the CMS across the UK, the current version, mounted on MS Access, is now, de facto, a national conservation management system. As its use becomes more widespread CMS plans are beginning to function as an evidence-based library of best practice for exchanging practical know how between users.

Data model of a conservation management system (CMS)

A CMS is simply a recording and filing tool that aids and improves the way in which heritage green assets are managed and kept in a favourable condition. Its prime function is to keep track of the inputs, outputs and outcomes of projects to meet measurable objectives. The aim is to promote efficient and effective operations, and allow recording of the work that was done and reporting on whether or not the objective was achieved. A CMS also enables the exchange of information about methods and achievements within and between organisations. These are essential components of a CMS of any scale, whether a national park, or a village pond.

Technically, a CMS is a project-based planning and recording system aimed at managing conservation features within acceptable limits of variation. A feature is any component of the environment that has to be managed e.g. a footpath or a species. A 'project' is simply a programme of work leading to an output e.g. 'construct a footpath', 'patrol an area' or 'record a species'. Projects are work plans that control specific factors that help or impede the attainment of management objectives. Each project includes a description of a process, e.g. the work to be done, when and where it is to be done and the inputs of resources required. When a project is completed, what was actually done is recorded. This is an output. The outcome of a CMS is the state of the feature at the end of the project and is measured by performance indicators. Performance indicators are quantitative or qualitative attributes of the features e.g. numbers of a species, and they are measured by special monitoring-projects in order to gauge success in reaching the management objectives. Copies of all projects with their inputs, outputs and outcomes are retained in the CMS to provide a progress- register, and an archive to support managerial continuity.

In summary, the prime function of a CMS is to enable conservation managers to control the operational functions of a management plan as a feedback system or work-cycle by:-

identifying and describing, in a standard way, all the tasks required to control the key factors (positive of negative), which influence the condition of the features, and thereby maintain the features in a favourable condition; producing and budgeting various work programmes to control the factors, for example five-year plans, rolling- plans, annual schedules, financial schedules, and work schedules for specified categories of staff; providing a site/species monitoring system to check the effectiveness of the plan against the specified objectives; facilitating the exchange of management information by reporting, within, and between, sites and organisations; using feedback from monitoring to improve the management system. The sequence of identifying features, setting objectives, and then selecting the factors to be controlled by projects with scheduled work plans, comprises a management plan.

The most effective way of organising a CMS is to assemble it as a set of interlinked forms as a relational database. However, it is also possible to operate a management plan with a spread sheet or a collection of hyperlinked 'to-do' lists.

Diagram of the planning cycle of a CMS

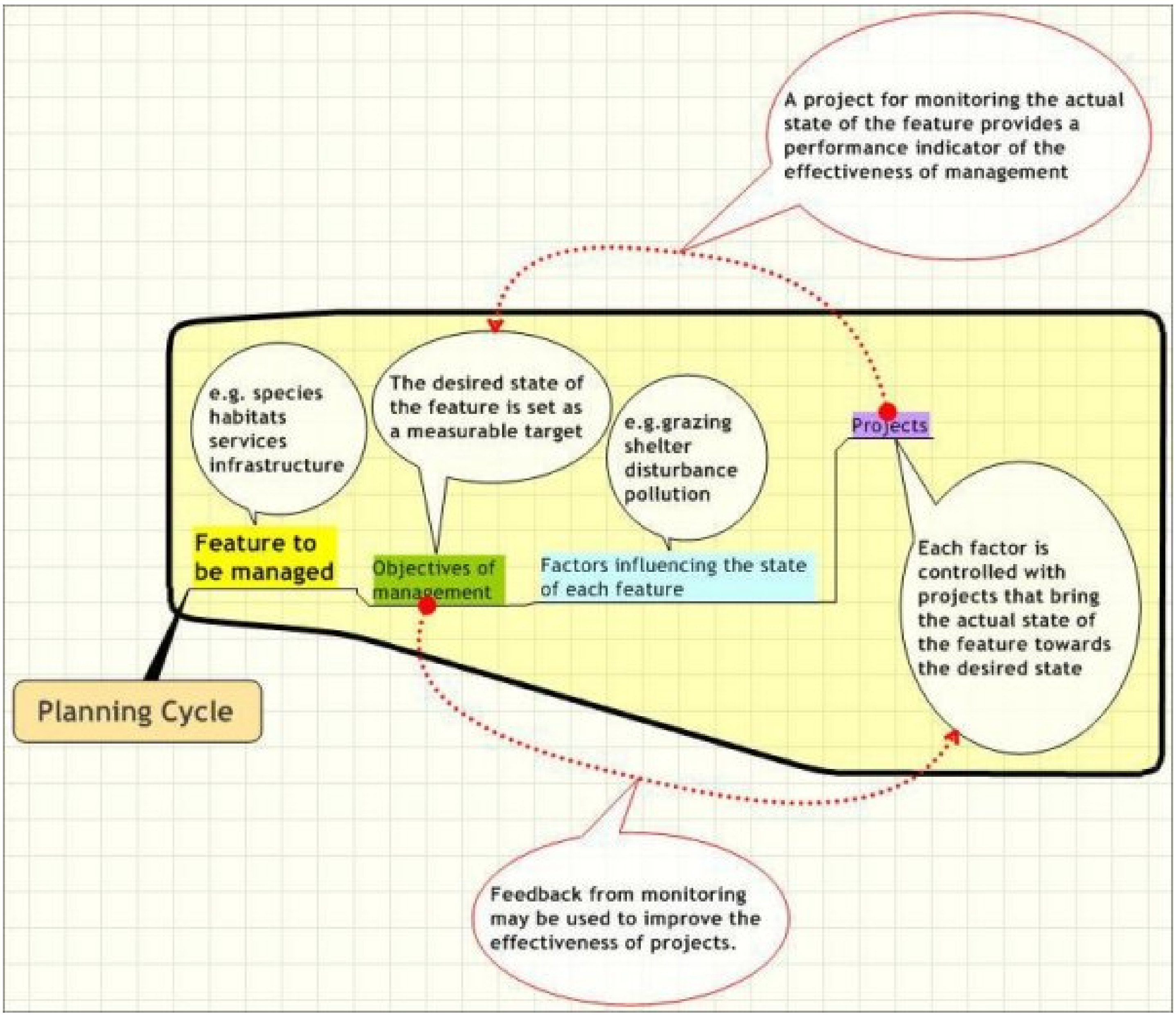
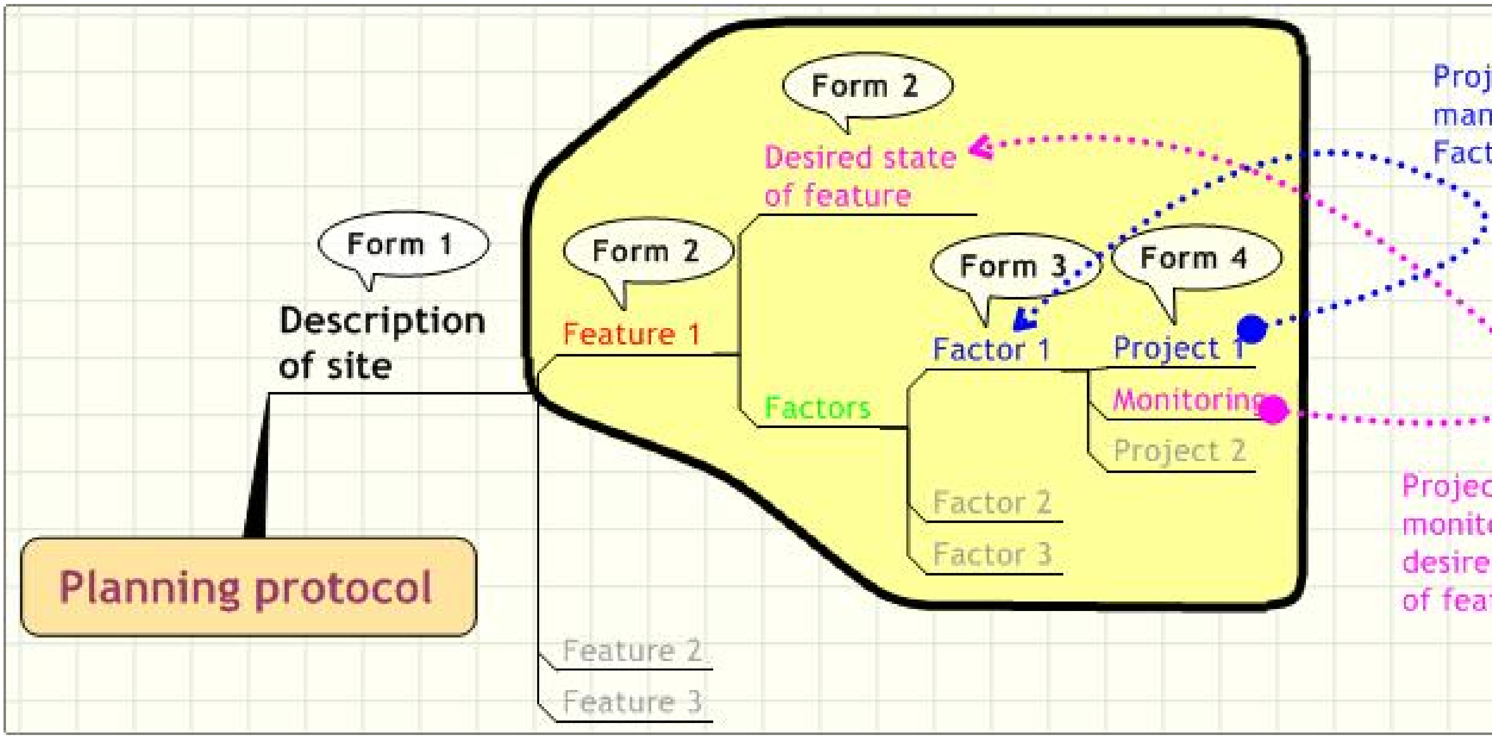


Diagram of the data structure of a CMS



20.5 Scope of conservation management

Conservation management implies the control of environmental and socioeconomic factors in order:

- to make more efficient use of materials,
- to recycle materials and energy that are vital to human survival,
- to restore derelict land
- and to maintain the capacity of ecosystems, which are the basis of all economies, to renew and grow.

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Since the first Global Environment Summit in 1992, national strategies are now commonly in place to integrate regimes of conservation management within and between industry sectors and communities to meet appropriate environmental, economic and social objectives. The practical aim is now to turn these strategies into operational systems and so balance exploitative management of natural resources with their conservation management. The goal is to provide the principles and tools to soften the clash between Earth's ability to sustain life and the character of its human occupancy. This means developing methods for biological conservation management alongside softer technological organisations for production (natural economy) and 'green' legislative actions for the organisation of people for production (political economy). The global educational topic-framework, which links conservation management with exploitative management, has been defined as 'cultural ecology'. It is within this area of knowledge that conservation management systems can be seen to require more than the scientific input of conservation biology. The essential feature of conservation management programmes is that they are part of the linkages between environmental, social and economic progress; between peace and security; between productivity of environment and community; and between sustainability and the renewal and extension of democracy. This is a roundabout way of saying that conservation management is about working on behalf of the wild to restore a culture, where people live and think as if they were totally engaged with their place on the planet for the long future.

20.6 Fundamental scientific questions

It is commonplace to hear conservation managers stress that they are really naturalists who do their best to apply good science to ecosystems that are unique in each case history. No two nature sites share the same history and factors limiting their biodiversity. They will differ with respect to time lags and non-linear responses to a given intervention. From this point of view conservation systems have much in common with the management systems of farmers and gardeners with regards uncertainties of the effects of inputs. Because of the internal complexity of ecosystems, science has yet to answer fundamental question that were posed by Darwin regarding the factors that control relative abundance of species, with respect to space, time, pattern, food chains and population dynamics. Every nature reserve is likely to have some or all of the following questions unanswered. They are fundamental questions in ecological science that underpin all conservation management systems.

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