# Essentials of Environmental Science

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# Essentials of Environmental Science

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# Chapter 1 Learning Skills

## Chapter Outline



Tkachenko, V. (2012). Nature landscape Ukraine. [JPG].
Retrieved from https://commons.wikimedia.org/wiki/File:Nature-landscape-ukraine-zaporizhzha20120707_0025-Edit_(8079228023).jpg.

### Learning Outcomes

**After studying this chapter, you should be able to:**

- Define environmental science
- Understand why it is important to study environmental science
- Develop an individual learning plan
- Understand the advantages of time management
- Practice active reading
- Learn to use critical thinking
- Recognize the importance of evaluating your sources

# 1.1 Studying Environmental Science

## What is Environmental Science?

Environmental science is the interdisciplinary and dynamic study of the interaction of the living and nonliving parts of the environment with special focus on the impact of humans on the environment. The study of environmental science includes circumstances, objects, or conditions by which an organism or community is surrounded and the aggregate of social, historical and cultural factors that influence the life of an individual or community (NSF, 2009).

## Why Study Environmental Science?

The need for equitable, ethical, and sustainable use of Earth's resources by a global population that nears the carrying capacity of the planet requires us not only to understand how human behaviors affect the environment, but also how human behavior changes in response to changes in the environment or perceptions of environmental status (Nuckols, Ward & Jarup, 2004). Large fraction of our environmental future depends on our ability to understand and evaluate evidence-based arguments about the environmental consequences of human actions and technologies, and to make informed decisions based on those arguments.

From global climate change to alterations in land-use patterns driven by population growth and development, Earth is becoming a different planet—right before our eyes (Nuckols, Ward & Jarup, 2004).The complicated and global scale of connectedness and rates of environmental change are beyond anything in recorded human history. Our challenge is not simply that things are changing fast; there is large uncertainty as to how fast and to what consequences. Human impacts have created a situation without precedent on this planet. Neither current nor past rates of change are dependable guides to what might occur in the future.

The way forward requires an improved understanding of Earth's complex environmental systems; systems characterized by interactions within and among their natural and human components that link local to global and short-term to long-term phenomena, and individual behavior to collective action. The complexity of environmental challenges demands that we all participate in finding and implementing solutions leading to long-term environmental sustainability.

## 1.2 Effective Learning and Reading

Regardless of your age or educational background, you can always cultivate your learning skills. The following insights are here to help you get off to a good start so that you can enhance your chances of being a skilled learner in whatever subject you choose to study (Gould Library, 2009a, 2009b, 2009c, Vancouver Island University, n.d.)

FIGURE 1.1

Students study at Shree Sahara Bal Primary School, Pokhara , grade1, Pokhara, Nepal.

Holmes, J. (2013). Students study at Shree Sahara Bal Primary School, grade1, Pokhara, Nepal. [JPG]. Retrieved from https://www.flickr.com/photos/dfataustralianaid/10727334216.

**Discipline is your key to success**. It is the ability to do what you're supposed to do when no one is looking. Discipline means making a total commitment to your studying plans, and schedules (ERIC, 1996). You've probably had an experience you're proud of where you've disciplined yourself to do something well (such as maintain an exercise schedule) or break a bad habit (such as smoking).

**Set study goals**. Setting goals is the best way to motivate yourself to study effectively. When you have a specific goal in mind you know what you want to achieve, and that makes it easier to achieve it. Setting study goals enables you to study with a purpose. Starting every study assignment with specific study goals gives focus to your work. Make a list of the tasks you must complete to achieve each goal. Note how much time you need to complete each task. Arrange your tasks in order of importance. Plan to spend a specific study period completing your study tasks. Use a check list to record your progress as you complete your tasks.

**Improve your concentration**. Accepting the fact that we can only do one thing at a time can improve our concentration when we sit down to do our schoolwork or other assignments. Acknowledge your concentration span. How long can you study before your mind wanders to something else? Fifteen minutes, twenty-five minutes? When you schedule your time, schedule mini-breaks that coincide with the time you're most likely to lose your concentration. Getup, stretch, get a drink of water or a breath of fresh air. When scheduling your mini breaks, make sure to stick to them. A 10-minutebreak shouldn't end up lasting a half hour.

**Minimize distractions**. If possible, you should work in a well-structured study space, with books and materials at hand. Before studying, spend a few minutes to set up your study space. Get a comfortable chair and face it towards a bare wall. Avoid facing windows. Clear your desk or table space of objects except those used for your study. This will minimize visual distractions.

**Respect your study time**. Help others to be mindful of the importance of your study time. Inform as many people as you can of your scheduled study time. This will help avoid the distraction of unexpected visitors and the telephone ringing.

**Manage your time**. Time management starts with being able to:

- Set goals and make priorities. This gives you a sense of what has to be done and when. Do important things first. Important things become pressing and use up more of our time when we avoid doing them.
- Say "No". There will be many interruptions and requests for your time. Anything that is not in your schedule, can be scheduled later. Start and stop specific activities at predetermined times. This enables you to concentrate on the task at hand.
- Make "to do" lists and schedules.

Before organizing your study time examine your daily routine including meals, travel, work, appointments, etc. How much time does it take for each task? Now decide how much study time you need, when you want to study, and how studying fits in with the rest of your activities.

<u>Daily "To Do" List</u>. Get in the habit of making a daily 'to do" list that combines your scheduled activities and the important things you want to do that day. After listing what you want to do, code the most important items and make sure you give them priority over less important items.

<u>Weekly Schedules</u>. To decide what is important, you need to know your week's schedule. Start each week by making a schedule. Fill in work time, study time, important events, etc.

<u>Monthly Schedule</u>. A monthly schedule can help you look more broadly at what you want to accomplish. The task you list on your monthly schedule can be incorporated into your weekly and daily schedules.

At the end of each day, week or month review your schedules. Observe how well your time schedules work for you. Make adjustments as needed.

**Forget learning styles: learn in more than one way**. There is no research evidence to support learning styles. You learn in many ways and you need to use a variety of methods to learn. Focus on learning in more than one way such as describing what you have learned to a friend, drawing a diagram, writing out your notes, or watching a video of a concept. Learning in many different ways will allow for storage of information in various regions of the brain. Figure out which strategies work best for you!

**Determine distinctiveness**. Figure out what makes a concept very unique or different (figure out the similarities and differences in new concepts so your brain can remember better).

**Make meaningful connections**. Create a visual connection of concepts, topics and components to each other. This helps you see the relationships between ideas and helps the brain learn better. Draw a map, a flowchart or a diagram to help see all the pieces and how they relate.

**Practice appropriate retrieval and application**. Don't memorize isolated facts (you can't learn remember it a longer time if you memorize many facts that are not connected), instead figure out ways to remember what you need to know and then apply it. Practice and study related to how your teacher will want content to be recalled.

**Generate questions as you are reading**. If you can find the answers to your questions, this would be better. Your brain will process the readings much better and you'll make meaning about the content. If your instructor gave some questions to consider, write out the answers as you are doing the readings. Or you can write possible test questions (with the answers) on your reading. Anytime you are thinking about questions when you are reading – will help you actively read!

**Make a summary note of your reading**. When you put in your own words what you have read, the brain will remember it better! After you have read a chapter or an article, write a one paragraph summary. Pretend you are writing your paragraph for someone who has not read the reading.

**Teach what you have learned to a friend**. The best way to learn something is to teach it to someone else – someone who doesn't know about the topic. Break down the concepts into your own words and find a way to share that learning with someone else (e.g., podcast, blog, group discussion). This is an excellent way for the brain to learn and encode new knowledge.

FIGURE 1.2

The best way to learn something is to teach it to someone else.

**Repeat the information.** Repeating is necessary in the memory process. Retrieval becomes quicker and easier the more we repeat or use the information.

**Enhance your wellness**. Make a healthy breakfast, lunch, or dinner and enjoy it with a friend. Eating well can help increase your energy level so you're ready to focus, and spending time with others can help reduce stress and anxiety. Take 10-minute activity breaks to reach 30 to 60 minutes of physical activity each day. Scheduling physical activity into your day can help lower stress and increase mental alertness.

### Table 1.1:

| READING WELL |
| --- |
| But I already know how to read!<br>Of course you do! But just as games get more and more complicated as you level up, so also reading means more and more things as you progress through your education. The authors whose texts you read in college, whether the texts are fact or fiction, are engaging in a slow-motion conversation on a topic. Your goal is to listen carefully to the author's side of the conversation so that you, too, can participate in the conversation. You don't want to simply parrot back what other people have said in the conversation, and you don't want to talk about something completely irrelevant. Instead, you want to listen (read) carefully and then contribute to the conversation in a meaningful way. |

**Read critically**. Critical reading involves more than simply understanding the information that the text conveys. That is the first step. But reading critically requires reading actively, in constant conversation with the text as you discern not only what it says, but how it says it. In the end, according to Dan Kurkland, you want to know three things:

- What the text says - information conveyed
- What the text does - purpose and techniques
- What the text means - interpretation in context

To help you do this, take notes as you are reading. The goals is to give yourself ways to find patterns and key moments in the text. This is your initial conversation with the author.

Make notes that:

- summarize key sections of the text
- mark important structural elements of the text,
- ask questions of the text,
- indicate places where you would like to go back and follow up on an allusion or citation,
- mark the most important phrases or sentences that you might want to quote later.

**READING WITHOUT PRINTING**

While reading on a screen may not be as appealing as reading on printed paper, there are several advantages

- It uses less paper and (even more importantly) less toner.
- You can take notes that are searchable and organizable.
- You can have multiple pages open at the same time on computer screens, which reduces flipping back and forth to look at a key chart or bibliography.

**Evaluate your Sources**. Essentially, evaluating a source means passing judgment on it, not only in terms of whether you agree or disagree with the point that the author is making, but in deciding what kind of source you are dealing with. It's important to use the appropriate kind of source in certain situations. For example, if your professor requires that you use only scholarly journal articles as sources for an assignment, you need to know how to identify that kind of source. Identifying the kind of source may help you in deciding how to judge its content as well.

One of the first things that you should look for in any source material is the author. Anonymous sources should be considered suspect until you have verified the information they contain. Many journals, magazines, and books will not only include the author's name, but give a brief description of who the author is and what his/her credentials are for writing on the subject. If you need more information about the author, you might consult a directory (there are directories for specific professions) or do a web search for information about the author.

It's always important to know where an author got his/her information. An author should cite the sources for particular information in the text or list references used in a bibliography at the end of the work. Factual information used to strengthen the author's argument that is given without a source should be verified before you use it to strengthen your own argument.

You should also notice where the information has been published or who published it. In the case of a book, check the press that published it. A scholarly or university press differs from a commercial press in its goals and stringency. Self-published work, whether in print or on the web, should be examined carefully. If you are looking at an article, notice if it has been published in a scholarly journal or a popular magazine. You can usually tell by looking at the publication. The differences between the two kinds of publication are important. Scholarly journals are refereed, which means that all articles published by them must be approved by a group of known scholars in the field (called "referees"). Popular magazines sometimes report research, but their coverage is at one remove from the actual research, so the description of the research may be very general or may even misinterpret the work. Try to find the actual research if you can. Always check the date of publication. New research often disproves old.

Always be aware of any *bias* on the part of the author. Bias alone does not disprove a thesis, but it may cause the author to ignore problems in his/her argument. Bias can also result in a misinterpretation or a narrow interpretation of the facts. There are also authors who deliberately misrepresent facts and ideas.

**Cite your sources**. Citing your references can be time-consuming, but here's why it's important:

- Citing your sources helps you to avoid plagiarism.
- Readers can go back and look at your sources if they'd like to follow up or read further.
- By demonstrating how widely you've researched a topic, your own argument ends up being more credible. Citations can show you've considered a wide variety of opinions when forming your own argument.
- Citing is standard practice in academic conversations. Scholars have been debating ideas through written works for years and citing is a way of respecting those who've engaged in the topic before you.

# 1.3 References

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# Supplementary Images

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# CHAPTER 2 Environmental Concerns, Dimensions, and Worldviews

## Chapter Outline



FIGURE 2.1

Indigenous people face many problems including lack of human rights, exploitation of their traditional lands and them- selves, and degradation of their culture. The picture shows an indigenous girl of Terena tribe.

Campanato, V. (2007). Terena003 [JPG]. Retrieved from https://commons.wikimedia.org/wiki/File:Terena003.jpg

## Learning Outcomes

After studying this chapter, you should be able to:

- Explain the concept of sustainability and its social, political, and cultural challenges
- Evaluate the main points of environmental ethics
- Describe the concept of environmental justice
- Differentiate between developed and developing countries

# 2.1 Environment and Sustainability

## Making Sense of Sustainable Development

Sustainability is the buzzword of our time. Everyone from policymakers, to urban planners and retail executives seem to have adopted the term. It is the in-vogue prefix for anything from corporate environmental reports to travel agents' package-tour promotions (EEA, 1997). To paraphrase economist Milton Friedman, we are all committed to sustainable development now. But what may be an advertiser's dream can be a local authority's nightmare. Is the concern with sustainability just a passing fad? Or does it signify an emergent cultural revolution? Do we all mean the same thing by sustainability or sustainable development? Do we all share the same premises and have the same goals? Or will different interpretations and different agendas result in conflicting policy interpretations, priorities and practices? Given the welter of confusion surrounding the concept, many local authorities might be forgiven for dismissing the validity or utility of the concept as an unnecessary complication for their work. This chapter unpacks the concept of sustainability. Writ large, the concept alludes not only to the ecological crises at hand but to wider social, political, and cultural challenges which will require the development of new methods, skills, and attitudes. Clarity on the subject, and the values, premises and agendas that lie tucked behind it, is essential to the accomplishment of sustainability goals. To a large degree this area of critical analysis has been left neglected in the stampede to jump aboard the sustainable development bandwagon. Critics argue that for sustainable development to be regarded merely as the *summum bonum* of human existence is to render it meaningless. The trade-offs and choices implicit in the 'search for sustainability' must be made transparent to generate widespread popular support for the need for transformation. There will no doubt be winners and losers in the process and this must be communicated honestly to prevent future conflicts. These and other themes are touched on in this chapter and recur in the rest of the text. This chapter concerns itself with the questions: What are the issues driving the sustainability movement? What are the controversies? And what do they mean?

### Taking The Long View: Sustainability in Evolutionary and Ecological Perspective

In evolutionary terms there is no such thing as sustainability — at least as far as our species is concerned. Of the different forms of life that have inhabited the Earth in its four thousand million year history, 99.9% are now extinct (EEA, 1997). Against this backdrop, the human enterprise with its roughly 300,000-year history barely merits attention. As Mark Twain, the American novelist once remarked, if our planet's history were to be compared to the Eiffel Tower, human history would be a mere smear on the very tip of the tower. But while modern humans (*Homo sapiens sapiens*) might be insignificant in evolutionary terms, we are by no means insignificant in terms of our recent planetary impact. A 1986 study estimated that 40% of the product of terrestrial plant photosynthesis — the basis of the food chain for most animal and bird life — was being appropriated by humans for their use. More recent studies estimate that 25% of photosynthesis on continental shelves (coastal areas) is being used to satisfy human demand. Human appropriation of such natural resources is having a profound impact upon the millions of other species which are also dependant upon them. Ecologist, William Catton has estimated that current rates of human resource extraction are 10,000 times the rates of natural resource regeneration; these are showing no signs of abating. More worrying still is the fact that human impact appears to be placing the planet itself into reverse gear. One of the basic tenets of evolution is that the generation of new forms of life outstrips the extinction of older species by a wide margin thus ensuring strong biological diversity. Scientists believe, however, that for the first observable time in evolutionary history, another species — *Homo sapiens sapiens* — has upset this balance to the degree that the rate of species extinction is now estimated at 10,000 times the rate of species renewal. Human beings, just one species among millions, are literally crowding out the other species we share the planet with. Evidence of human interference with the natural world is visible in practically every ecosystem from the presence of CFCs in the stratosphere to the artificially changed courses of the majority of river systems on the planet. It is argued that ever since they abandoned nomadic, gatherer-hunter ways of life for settled societies some 10,000 years ago, humans have continually manipulated their natural world to meet their needs. While this observation is a correct one, the rate, the scale and the nature of human-induced global change — particularly in the post-industrial period — is unprecedented in the history of life on Earth.

There are three primary reasons for this.

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

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

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

## The Significance of Such Biospheric Intervention

The cumulative effects of these human interventions are gradually beginning to manifest themselves. Collectively these phenomena signify a major discontinuity, a tectonic shift in our relation with the biosphere. In terms of their message, they amount to what Norman Myers calls 'a whole flock of miner's canaries singing with decibels of warnings.' As Clive Ponting, the historian, has noted, humans are distinct from all other species in their relationship to the ecosystem in two ways. 'First, they are the only species capable of endangering and even destroying the ecosystems on which they depend for their existence. Second, humans are the only species to have spread into every terrestrial ecosystem and then, through the use of technology, to have dominated them.'

Recent human development patterns have not only affected ecological systems but are also rapidly changing social systems. Arguably two of the most powerful forces of societal change in modern times have been:

- colonialism, with its lasting legacy of unequal political and economic relations between and within countries; and
- scientific and technological development, which has changed virtually every aspect of contemporary life.

These and other forces have contributed to a highly polarized world where disparities in wealth and income (see Figure2.2).

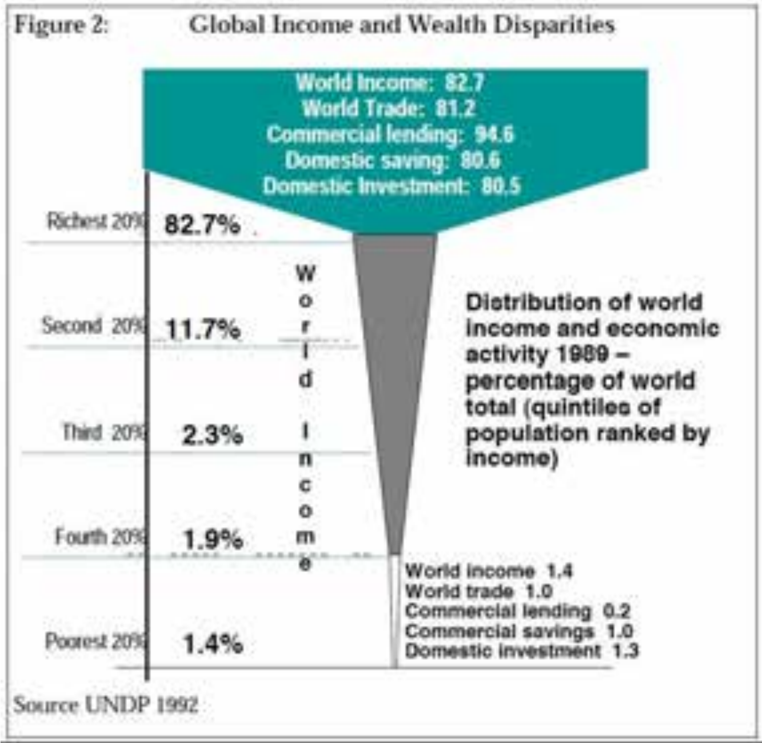


FIGURE 2.2

Power and status, are deepening and continue to be marked by differences in, inter alia, gender, race and ethnicity, and national origin. Viewing the human predicament in ecological and evolutionary perspective is fundamental to an understanding of the significance of current changes. Taking the long view shatters the complacency of business-as-usual attitudes that 'unsustainability' is just a phase humanity is going through. Despite the complexity and uncertainty of global changes, there appears to be scientific consensus on most of the following three points:

1. first, the magnitude of the impact that humans, a juvenile species in evolutionary terms, are exerting on life-support systems;
2. second, as Gaia theoreticians — who view the planet as a self-regulating system — point out: the Earth is indifferent to humans, it will ultimately recover, even though the timescale will be eons;
3. the need for change to ensure a future for human beings.

### The Evolution of Sustainability Itself

While Our Common Future, the report of the World Commission on Environment and Development (commonly known as the Brundtland Commission) is widely credited with having popularized the concept of sustainable development, it does in fact have a longer lineage (EEA, 1997). The year 1972 was a watershed in marking both the first International Conference on the Human Environment in Stockholm and the publication of the provocative report Limits to Growth by the Club of Rome which highlighted the imminent threat of 'overshoot' (a systems-analysis term for exceeding the carrying capacity). Throughout the 1970s and 1980s a steady stream of books and reports began to appear, preoccupied with the question of environment and development. This stream would turn into a deluge in the sustainability friendly 1990s. The World Conservation Strategy, the manifesto published collectively in 1980 by the World Conservation Union (IUCN), the United Nations Environment Programme (UNEP — set up after the Stockholm conference), and the World Wide Fund for Nature (WWF), stands out as an early — but at the time largely overlooked — international attempt at mobilizing public action to address emergent environmental challenges.

**(Selected) Definitions of Sustainable Development**

**Our Common Future** (Brundtland Commission Report), World Commission on Environment Development, 1987
1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
2. ... sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the orientation of the technological development, and institutional change are made consistent with future as well as present needs.

**Caring for the Earth** (IUCN, WWF, UNEP, 1991) Sustainable development means improving the quality of life while living within the carrying capacity of supporting ecosystems.

**Maastricht Treaty on European Union** (Article 2, Treaty on European Union, 1992) (Sustainable development is) a harmonious and balanced development of economic activities, sustainable and non-inflationary growth respecting the environment.

**Blueprint for a Green Economy ('Blueprint 1'). David Pearce, et al (1989), Earthscan, London** Weak Sustainability: Only the aggregate of stocks of capital, regardless of their type, has to be held constant for future generations; these forms of capital are completely substitutable for each other. 'It is the aggregate quantity that matters and there is considerable scope for sustituting man-made wealth for natural environmental assets'

More recently, environmentalists have argued that the intellectual history of the concept of sustainability can be traced back to the terms 'stationary' or 'steady-state economy' used by 19th century political economists. For John Stuart Mill, the 19th-century political economist, 'stationary' was not a static concept but referred to a balance between production and natural resources implying equality of access to natural resources for successive generations. These concerns are not only to be found in dissident western intellectual traditions but can be traced in the oral histories of indigenous cultures. For example, the principle of intergenerational equity is captured in the Inuit saying, 'we do not inherit the Earth from our parents, we borrow it from our children'. The Native American 'Law of the Seventh Generation' is another illustration. According to this, before any major action was to be undertaken its potential consequences on the seventh generation had to be considered. For a species that at present is only 6,000 generations old, and whose current political decision-makers operate on time scales of weeks, or five years at most, the thought that other humans have based their decision-making systems on time scales of 300 years seems inspiringly sage but politically inconceivable.

### Conflicts and Controversies

At the beginning of this chapter the observation was made that sustainable development is not a self-evident concept but a politically contested one. Despite a plethora of varying definitions, at its core, sustainability refers to three simple concerns:

- the need to arrest environmental degradation and ecological imbalance;
- the need not to impoverish future generations;
- the need for quality of life and equity between current generations.

Added up, these core concerns are an unmistakable call for transformation. Business-as-usual is no longer an option. Social institutions — including economic systems and political arrangements — cannot continue as they are. This is not an agenda for the faint-hearted. Little wonder then that ever since Our Common Future popularized what had hitherto existed on disciplinary margins or NGO agendas, there has been an avalanche of books, reports, and articles on the subject, addressing sustainable development from every conceivable angle. In the ensuing war of definition, almost 300 different interpretations of the concept have been identified. These differing — sometimes conflicting — interpretations are not accidental. They are the products of conflicting worldviews, differing ideologies, varied disciplinary backgrounds, opposing knowledge traditions, value systems and vested interests. Such differences in understanding and approach make consensus towards common agendas difficult.

Furthermore, in a sharply divided world it is not uncommon for the rich and powerful to have one agenda; and the poor and under-privileged to have another. Why the need for conceptual clarity? But why does this matter? Is it not futile to quibble over conceptual definitions when the key issue is to devise strategies and set targets to put the concept into practice? While action is urgently needed, understanding the concept and agreeing upon principles for action is paramount. Two examples bring this point home. The first is from Canada, one of the first countries to embrace 'sustainable development' as official national policy. In 1992 a three-volume survey of how Canadian municipalities were attempting to translate sustainability in the urban context found a spectrum of definitions of sustainable development formulated by municipal officials. The author concluded that the exercise underscored how 'poorly the concept is understood and put to practice, despite all the rhetoric since the Brundtland report'.

The second example comes from the UN Secretary-General's review of global progress on sustainable development since UNCED. The report notes that one of the constraining factors to further progress has been that: '... not all Governing Bodies of international organizations, even within the UN system, have the same understanding of the concept of sustainable development. Some have adopted programs of environmentally sustainable development, others have called for sustainable human development while others have talked of conservation or other types of environmental plans. This has led to some confusion regarding the core issues of sustainable development.'

Evidently, clarity about the concept is crucial when it comes to selecting which issues are to be emphasized, whose needs and interests are to be prioritized, and who is to be involved in the decision-making. This in turn informs what framework is to be set and what policies and instruments are to be employed. Such considerations matter because the defining of issues and the negotiation of interests is not an apolitical process, it is an intensely political one. Several analysts have emphasized this point: '... the realization of environmentally sustainable strategies is not simply a problem of technology or ecosystemic understanding, but of politics, institutions and the articulation and implementation of public policy'.

Two controversial examples serve to illustrate this point of the power of definition and, subsequently, policy formulation.

**What is more unsustainable: population growth or car growth?**

The first case relates to those two favorite bogies of many environmentalists: population growth and cars. Population growth rates, in relation to available resources, have long been held to be a key source of environmental degradation (EEA, 1997). Population control has therefore been a central focus of many international aid programmes, which use an assortment of incentives and inducements to lower fertility in poor countries. Car growth, on the other hand, is growing four times as fast as the human population. There are, however, no population control programmes for cars. Traffic growth targets are seldom set (or seriously implemented) and policy makers seem incapable of arresting the inexorable growth in private vehicles. Experience has shown that restrictions have been opposed by the automobile industry and western consumers alike as an attack on free trade and personal freedoms respectively. Critics charge that it is therefore evidently easier to control the fertility of the poor in Southern countries than the mobility of car-dependent consumers in Northern countries. Such policy choices beg the question: whose interests are being served, and at whose cost?

***Whose Common Future?***

The case of Our Common Future is also instructive here. While the report is credited for catapulting the issues of environmental degradation and unequal development onto the international stage, it was also profoundly critiqued for its ambiguity and unwillingness to draw out the policy implications of its own analysis. It condemned the environmental impact of economic growth; but called for more growth. It deplored growing inequality in the world; but was silent on resource distribution. Critics charged that the report sought to be 'all things to all people', obscuring real world issues of power, conflict, and responsibility. While some people identified it with the message of ecological integrity, economic transformation and social justice, others identified it with the promise of sustained growth, that it was possible to be 'green and rich at the same time'. No doubt any report that was endorsed by free-market Heads of State and antipoverty activists alike was bound to suffer from some degree of schizophrenia. In sum, the impassioned debates surrounding the Brundtland Commission report, and the political confrontations at the later Earth Summit (Rio 1992), underscore the fears and divisions at the heart of the sustainability debate. It is these that are driving — or hindering — different sustainability agendas .

## The Flashpoints

If the core elements of sustainability — ecology, economy, and equity — be regarded as the tips of a triangle, then it is the relationship between ecology and economy, and economy and equity respectively, that constitute the flashpoints in the sustainable development debate. More specifically, the themes are: the weakness of economic models, the nature of growth, the culture of consumption, and equity.

### Environment or Economy?

Perhaps the most evident clash of interests and competing worldviews is between ecologists and economists (EEA, 1997). In everyday life, sustainability choices are typically described as being about economic growth or environmental quality, conservation or jobs. Framed in such a way, it is no secret that precedence is usually given to immediate economic needs. Critics argue, however, that the choice is a false one: the environment is not only the 'long-term economy' but a healthy environment is a precondition for a healthy economy. The competitive edge gained by those countries who have shrewdly invested in strong environmental standards and nurtured ecologically responsible industry supports this point. Nevertheless, there is no fudging the very real differences that lie at the heart of the environment-economy dispute. Ecologist Bill Rees argues that sustainability is a 'more complex problem from the ecological perspective than it appears to be from the economic mainstream'.

Expansion-orientated business and industry call for 'sustained growth' environmental scientists scorn such notions in a world of limited resources and oppose 'unfettered expansion of economic activity in rich nations'. As one green economist states: 'the conflict between current economic growth patterns and sustainability constraints hardly needs to be argued: it is the whole basis of the environmental crisis. If current patterns of economic growth were simply to continue ... environmental degradation will get worse'.

In recent years there has been strong criticism of mainstream (neo-classical) economics for its short-sightedness on environmental and social (e.g. equity, gender and culture) factors. This failing is not only inefficient, it leads to the 'externalizing' — or passing on to society or future generations — of environmental and social costs. Economic indicators such as GNP have also come under fire for their inadequacies in guiding ecologically viable economic policy. Above all it is the nature of growth, and the demands of a consumer culture for it — 'the notion that the role of a human being is to maximize his or her consumption'— that are irreconcilable with ecological objectives of respecting biospheric integrity in a context of rising population, rising consumerism, and rising environmental stress. It is this last issue that remains one of the central flashpoints in the environment-economy link. Positive steps towards a more balanced and ecologically sound relationship are, however, being made. For example, the development of industrial ecology with its focus on a circular rather than a linear economy, has found a receptive ear in progressive industry circles. Strides are being made in several areas to increase resource and energy productivity (make 'more with less') by factors of 4 to 10. These are being advocated by research institutes, lobbying associations and the European Commission to reduce both 'input' and 'throughput' in the economy. The discipline of economics itself is slowly being transformed by practitioners bringing in new thinking on ecological and social connections. For example, recent theorizing has focused on the need to maintain and enhance 'natural capital': the objective being to live off the income rather than deplete stocks. More generally, the environment-economy link has become part of political debate; it has even become fashionable to talk in terms of the 'triple bottom line': environment, economics and equity. Institutions such as the World Bank have also established units to study the challenges of environmentally sustainable development.

### Equity

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

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

92% cars
70% CO2 emissions
86% copper and aluminium
81% paper
80% iron and steel
48% cereal crops
60% artificial fertilizer

Countries such as China, Brazil, India, and Malaysia are, however, catching up fast (EEA, 1997). In such a situation, global consumption of resources and energy needs to be drastically reduced to a point where it can be repeated by future generations. But who will do the reducing? Poorer nations want to produce and consume more. Yet so do richer countries: their economies demand ever greater consumption-based expansion. (Parallel conflicts of interest can also be found at the local and national level.) Such stalemates have prevented any meaningful progress towards equitable and sustainable resource distribution at the international level. These issue of fairness and distributional justice remain unresolved, but high on the political agenda. It has both biophysical, social and economic dimensions. The social dimensions are the most politically contested and the assumptions lying behind talk of environment, development, equity, and sustainability need to be interrogated before a commonality of interests can be assumed. In practical terms this means that depending on the interpretation, policy choices could favor (one or in combination): technocratic solutions; (re)distributive measures; market-based instruments; individual value and lifestyle changes; or wide-scale economic and institutional reform.

## The Ecological Footprint

The Ecological Footprint (EF), developed by Canadian ecologist and planner William Rees, is basically an accounting tool that uses land as the unit of measurement to assess per capita consumption, production, and discharge needs (University of California College Prep, 2012). It starts from the elementary assumption that 'every category of energy and material consumption and waste discharge requires the productive or absorptive capacity of a finite area of land or water. If we (add up) all the land requirements for all categories of consumption and waste discharge by a defined population, the total area represents the Ecological Footprint of that population on Earth whether or not this area coincides with the population's home region.

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

Although the size of an Ecological Footprint, also termed Appropriated Carrying Capacity (ACC) would vary according to socioeconomic and technological factors one point is constant: the flows and capacities 'occupied' by one population are not available for another as these resources are finite. What does the Ecological Footprint tell us? Ecological footprint analysis can tell us in a vivid, ready-to-grasp manner how much of the Earth's environmental functions are needed to support human activities. It also makes visible the extent to which consumer lifestyles and behaviours are ecologically sustainable calculated that the Ecological Footprint of the average American is – conservatively – 5.1 hectares per capita of productive land. With roughly 7.4 billion hectares of the planet's total surface area of 51 billion hectares available for human consumption, if the current global population were to adopt American consumer lifestyles we would need two additional planets to produce the resources, absorb the wastes, and provide general lifesupport functions.

Ecological footprints have been calculated for numerous nations, cities, communities, and even individuals. The London-based IIED has calculated that London's ecological footprint is 120 times the size of the city. The footprint of the average Dutch person is slightly less at 3.3 hectares per capita but still import 'land services' fifteen times the territory of the Netherlands itself. The message of the ecological footprint is that lifestyles and behaviour, industrial production and trade, institutions and politics must change. Humanity must learn to live off the income of the 'natural capital', and maintain natural stocks rather than continuing to mine them. Wackernagel and Rees suggest that one way would be to focus 'more on living locally than on consuming globally.

## Connectivity

We live in a world characterized by connectivity, that is, bycomplex chains linking our everyday lives to distant strangers and ecosystems in far flung regions of the earth, we have no choice. In the end, we must adapt our thinking to a complex, connected model of the world and our place in it. Persisting with only simple, consumerist frames of understanding—"I look great!" "This tastes delicious!"—for a complex world of remote impacts and finite resources renders us increasingly vulnerable to episodes of what ecologists call system collapse, that is, to the sudden breakdown of ecosystem services we rely upon for our life's staple provisions. In the early twenty-first century, vulnerability to these system collapses varies greatly according to where one lives. A long-term drought in India might bring the reality of aquifer depletion or climate change home to tens of thousands of people driven from their land, while the life of a suburban American teenager is not obviously affected by any resource crisis. But this gap will narrow in the coming years. Overwhelming scientific evidence points to rapidly increasing strains this century on our systems of food, water, and energy provision as well as on the seasonable weather to which we have adapted our agricultural and urban regions. In time, no one will enjoy the luxury of remaining oblivious to the challenges of sustainability. Drought, for example, is one of the primary indices of global ecosystem stress, and arguably the most important to humans.

## Precautionary Principle

The precautionary principle is central to environmental sustainability (Kriebel et al., 2001). A 1998 consensus statement characterized the precautionary principle this way: "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically".

The precautionary principle has arisen because of the perception that the pace of efforts to combat problems such as climate change, ecosystem degradation, and resource depletion is too slow and that environmental and health problems continue to grow more rapidly than society's ability to identify and correct them. In addition, the potential for catastrophic effects on global ecologic systems has weakened confidence in the abilities of environmental science and policy to identify and control hazards. There are also the apparent contradictions of our regulatory process: if the laws governing toxic chemical release are effective, then why are mercury levels in freshwater fish so high that pregnant women should not eat them? How is it possible that human breast milk may not meet U.S. Food and Drug Administration contaminant limits for baby food? The great complexity, uncertainty, and potential for catastrophe from global climate change are among the strongest motivators for those urging precaution in environmental policy. The precautionary principle, by calling for preventive action even when there is uncertainty, by placing the onus on those who create the hazard, and by emphasizing alternatives and democracy, is viewed by environmentalists as a way to shift the terms of the debate and stimulate change.

The precautionary principle seeks to minimize the limitations of a risk assessment based regulatory policy by encouraging a search for alternatives whenever a potentially hazardous chemical is identified. If a clearly safer alternative exists, why accept even a small, highly uncertain risk? The Danish Environment Agency used just this logic in taking action to eliminate phthalates from toys. They said, in essence, that there is exposure to these compounds, there is animal toxicity data, the exposure is to children who by definition are particularly susceptible to many toxic substances, there are alternatives, and the product serves no necessary function. Considering all these factors, they concluded that the plasticizer should not be used in toys.

## Challenges to Environmental Sustainability

Organizations such as the World Commission on Environment and Development, the Millennium Ecosystem Assessment, and several others including the Intergovernmental Panel on Climate Change, the Organization for Economic Cooperation and Development, and the National Academy Report to Congress have all issued reports on various aspects of the state of society and the environment. The members of these groups are among the best experts available to assess the complex problems facing human society in the 21$^{st}$ century, and all have reached a similar conclusion: absent the enactment of new policies and practices that confront the global issues of economic disparities, environmental degradation, and social inequality, the future needs of humanity and the attainment of our aspirations and goals are not assured.

## Some Indicators of Global Environmental Stress

**Forests**—Deforestation and degradation remain the main issues. 1 million hectares of forest were lost every year in the decade 1980-1990. The largest losses of forest area are taking place in the tropical moist deciduous forests, the zone best suited to human settlement and agriculture; recent estimates suggest that nearly two-thirds of tropical deforestation is due to farmers clearing land for agriculture. There is increasing concern about the decline in forest quality associated with intensive use of forests and unregulated access.

**Soil** — As much as 10% of the earth's vegetated surface is now at least moderately degraded. Trends in soil quality and management of irrigated land raise serious questions about longer-term sustainability. It is estimated that about 20% of the world's 250 million hectares of irrigated land are already degraded to the point where crop production is seriously reduced.

**Fresh Water** — Some 20% of the world's population lacks access to safe water and 50% lacks access to safe sanitation. If current trends in water use persist, two-thirds of the world's population could be living in countries experiencing moderate or high water stress by 2025.

**Marine fisheries** — 25% of the world's marine fisheries are being fished at their maximum level of productivity and 35% are overfished (yields are declining). In order to maintain current per capita consumption of fish, global fish harvests must be increased; much of the increase might come through aquaculture which is a known source of water pollution, wetland loss and mangrove swamp destruction.

**Biodiversity** — Biodiversity is increasingly coming under threat from development, which destroys or degrades natural habitats, and from pollution from a variety of sources. The first comprehensive global assessment of biodiversity put the total number of species at close to 14 million and found that between 1% and 11% of the world's species may be threatened by extinction every decade. Coastal ecosystems, which host a very large proportion of marine species, are at great risk with perhaps one-third of the world's coasts at high potential risk of degradation and another 17% at moderate risk.

**Atmosphere** — The Intergovernmental Panel on Climate Change has established that human activities are having a discernible influence on global climate. $CO_2$ emissions in most industrialised countries have risen during the past few years and countries generally failed to stabilize their greenhouse gas emissions at 1990 levels by 2000 as required by the Climate Change convention.

**Toxic chemicals** — About 100,000 chemicals are now in commercial use and their potential impacts on human health and ecological function represent largely unknown risks. Persistent organic pollutants are now so widely distributed by air and ocean currents that they are found in the tissues of people and wildlife everywhere; they are of particular concern because of their high levels of toxicity and persistence in the environment.

**Hazardous wastes** — Pollution from heavy metals, especially from their use in industry and mining, is also creating serious health consequences in many parts of the world. Incidents and accidents involving uncontrolled radioactive sources continue to increase, and particular risks are posed by the legacy of contaminated areas left from military activities involving nuclear materials.

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

# 2.2 Environmental Ethics

The concept of ethics involves standards of conduct (University of California College Prep, 2012). These standards help to distinguish between behavior that is considered right and that which is considered wrong. As we all know, it is not always easy to distinguish between right and wrong, as there is no universal code of ethics. For example, a poor farmer clears an area of rainforest in order to grow crops. Some would not oppose this action, because the act allows the farmer to provide a livelihood for his family. Others would oppose the action, claiming that the deforestation will contribute to soil erosion and global warming. Right and wrong are usually determined by an individual's morals, and to change the ethics of an entire society, it is necessary to change the individual ethics of a majority of the people in that society.

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

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

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

## Sustainable Ethic

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

- The earth has a limited supply of resources.
- Humans must conserve resources.
- Humans share the earth's resources with other living things.
- Growth is not sustainable.

- Humans are a part of nature.
- Humans are affected by natural laws.
- Humans  succeed best when they maintain the integrity of natural processes sand cooperate with nature.

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

## Land Ethic

Aldo Leopold, an American wildlife natural historian and philosopher, advocated a biocentric ethic in his book, A Sand County Almanac (University of California College Prep, 2012). He suggested that humans had always considered land as property, just as ancient Greeks considered slaves as property. He believed that mistreatment of land (or of slaves) makes little economic or moral sense, much as today the concept of slavery is considered immoral. All humans are merely one component of an ethical framework. Leopold suggested that land be included in an ethical framework, calling this the land ethic.

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

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

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

Leopold had two interpretations of an ethic: ecologically, it limits freedom of action in the struggle for existence; while philosophically, it differentiates social from anti-social conduct. An ethic results in cooperation, and Leopold maintained that cooperation should include the land.

## Hetch Hetchy  Valley

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

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

FIGURE 2.3

Yosemite valley, California, USA.
Sullivan J. (n.d.) Yosemite Valley. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/Yosemite_National_Park#/media/File:Yosemite_Valley_-with_Half_Dome_in_the_distance.jpg.

limitless. However, the conservationists agreed with the rest of the tenets of frontier ethics, while the preservationists agreed with the tenets of the sustainable ethic.

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

"As to my attitude regarding the proposed use of Hetch Hetchy by the city of San Francisco. . . I am fully persuaded that… the injury…by substituting a lake for the present swampy floor of the valley…is altogether unimportant compared with the benefits to be derived from it's use as a reservoir.

"The fundamental principle of the whole conservation policy is that of use, to take every part of the land and its resources and put it to that use in which it will serve the most people." (Gifford Pinchot, 1913)

John Muir, the founder of the Sierra Club and a great lover of wilderness, led the fight against the dam. He saw wilderness as having an intrinsic value, separate from its utilitarian value to people. He advocated preservation of wild places for their inherent beauty and for the sake of the creatures that live there. The issue aroused the American public, who were becoming increasingly alarmed at the growth of cities and the destruction of the landscape for the sake of commercial enterprises. Key senators received thousands of letters of protest.

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

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

## The Tragedy of the Commons

In his essay, The Tragedy of the Commons, Garrett Hardin (1968) looked at what happens when humans do not limit their actions by including the land as part of their ethic (University of California College Prep, 2012). The tragedy of the commons develops in the following way: Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work satisfactorily for centuries, because tribal wars, poaching and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning (i.e., the day when the long-desired goal of social stability becomes a reality). At this point, the inherent logic of the commons remorselessly generates tragedy.

As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks: "What is the utility to me of adding one more animal to my herd?" This utility has both negative and positive components. The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1. The negative component is a function of the additional overgrazing created by one more animal. However, as the effects of overgrazing are shared by all of the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of -1.

The sum of the utilities leads the rational herdsman to conclude that the only sensible course for him to pursue is to add another animal to his herd, and then another, and so forth. However, this same conclusion is reached by each and every rational herdsman sharing the commons. Therein lies the tragedy: each man is locked into a system that compels him to increase his herd, without limit, in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in the commons brings ruin to all.

Hardin went on to apply the situation to modern commons. The public must deal with the overgrazing of public lands, the overuse of public forests and parks and the depletion of fish populations in the ocean. Individuals and companies are restricted from using a river as a common dumping ground for sewage and from fouling the air with pollution. Hardin also strongly recommended restraining population growth.

The "Tragedy of the Commons" is applicable to the environmental problem of global warming. The atmosphere is certainly a commons into which many countries are dumping excess carbon dioxide from the burning of fossil fuels. Although we know that the generation of greenhouse gases will have damaging effects upon the entire globe, we continue to burn fossil fuels. As a country, the immediate benefit from the continued use of fossil fuels is seen as a positive component. All countries, however, will share the negative long-term effects.

## 2.3 Categorizing Countries

The world's industrialized countries are undergoing many changes as they move to the later stages of the Industrial Revolution (University of California College Prep, 2012). 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 (Theis & Tomkin, 2015). 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.

Countries are categorized by a variety of methods. During the Cold War period, the United States government categorized countries according to each government's ideology and capitalistic development. 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 been discarded.

Current classification models utilize economic (and sometimes other) factors in their determination. One two-tiered classification system developed by the World Bank classifies countries as developing and developed. 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. A few countries, such as Israel, Kuwait and Singapore, are also classified as developing countries, despite their high per capita income. 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.

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.

# 2.4 Environmental Justice and Indigenous Struggles

## Environmental Justice

Environmental Justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (University of California College Prep, 2012). It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.

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 (University of California College Prep, 2012). 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. In the United States many of those in the federal government are pushing to exploit oil resources in the Arctic National Wildlife Refuge on the northern coast of Alaska. The "Gwich'in," an indigenous people who rely culturally and spiritually on the herds of caribou that live in the region, claim that drilling in the region would devastate their way of life. Thousands of years of culture would be destroyed for a few months' supply of oil. Drilling efforts have been stymied in the past, but mostly out of concern for environmental factors and not necessarily the needs of the indigenous people. Curiously, another group of indigenous people, the "Inupiat Eskimo," favor oil drilling in the Arctic National Wildlife Refuge. Because they own considerable amounts of land adjacent to the refuge, they would potentially reap economic benefits from the development of the region.

In the Canadian region encompassing Labrador and northeastern Quebec, the Innu Nation has battled the Canadian Department of National Defense (DND) to prevent supersonic test flights over their hunting territory. The Innu Nation asserts that such flights are potentially harmful to Innu hunters and wildlife in the path of such flights. The nature of Innu hunting includes travelling over long distances and staying out on the land for long periods of time. The Innu Nation claims that low-level supersonic fly-overs generate shock waves, which can irreversibly damage the ears and lungs of anyone in the direct flight path. They also claim that the DND has made no serious efforts to warn the Innu people of the possible dangers.

In the rainforest regions of Brazil, indigenous peoples of several tribes are working together to strengthen their common concern over the impact of large development projects on their traditional lands. Such projects range from the construction of dams and hydroelectric power plants to the alteration of the natural courses of rivers to provide commercial waterways. The government of Brazil touts development of the Tocantins-Araguaia waterway as a means to facilitate river navigation in the eastern Amazon. It will promote agricultural development in Brazil's heartland and in the eastern Amazon by providing access to markets of grains, fuel and fertilizers. However, the waterway will negatively impact fifteen indigenous peoples who object that the changes in the natural rivers will cause the death of the fish and animals upon which they depend for survival.

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.

# 2.5 Resources

## Summary

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

## Review Questions

1. Name some indicators of global environmental stress.
2. Define sustainability.
3. Explain the following terms: frontier ethic, land ethic, environmental ethic.
4. What are developed countries according to the World Bank classification?
5. Define environmental justice.

# 2.6 References

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# CHAPTER 3 Principles of Science

## Chapter Outline



FIGURE 3.1
Service botanist taking a water sample.
U.S. Fish and Wildlife Service Southeast Region. (2013). Service botanist Mara Alexander taking a water sample. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/File:Service_botanist_Mara_Alexander_taking_a_water_sample_(9666514088).jpg

### Learning Outcomes

After studying this chapter, you should be able to:

- Identify the shared characteristics of the natural sciences
- Understand the process of scientific inquiry
- Compare inductive reasoning with deductive reasoning
- Describe the goals of basic science and applied science

# 3.1 The Process of Science

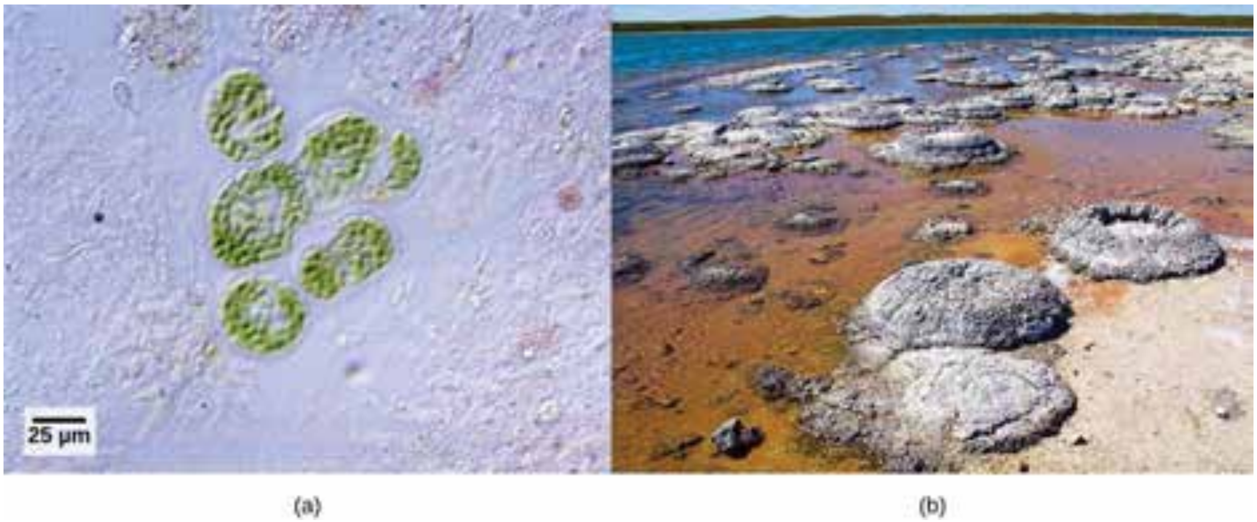



FIGURE 3.2
Formerly called blue-green algae, the (a) cyanobacteria seen through a light microscope are some of Earth's oldest life forms. These (b) stromatolites along the shores of Lake Thetis in Western Australia are ancient structures formed by the layering of cyanobacteria in shallow waters. (credit a: modification of work by NASA; scale-bar data from Matt Russell; credit b: modification of work by Ruth Ellison)

Like geology, chemistry and biology, environmental science is a science that gathers knowledge about the natural world (OpenStax College, 2013). The methods of science include careful observation, record keeping, logical and mathematical reasoning, experimentation, and submitting conclusions to the scrutiny of others. Science also requires considerable imagination and creativity; a well-designed experiment is commonly described as elegant, or beautiful. Like politics, science has considerable practical implications and some science is dedicated to practical applications, such as the prevention of disease (Figure 3.3). Other science proceeds largely motivated by curiosity. Whatever its goal, there is no doubt that science has transformed human existence and will continue to do so.

## The Nature of Science

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

Science is a very specific way of learning, or knowing, about the world. The history of the past 500 years demonstrates that science is a very powerful way of knowing about the world; it is largely responsible for the technological revolutions that have taken place during this time. There are however, areas of knowledge and human experience that the methods of science cannot be applied to. These include such things as answering purely moral questions, aesthetic questions, or what can be generally categorized as spiritual questions.

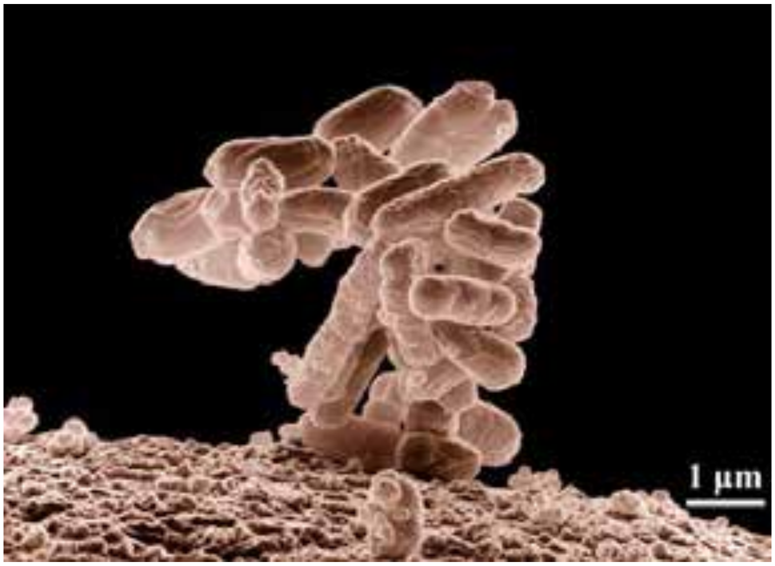



FIGURE 3.3

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

Science cannot investigate these areas because they are outside the realm of material phenomena, the phenomena of matter and energy, and cannot be observed and measured.

The **scientific method** is a method of research with defined steps that include experiments and careful observation. The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses (OpenStax College, 2013). A **hypothesis** is a suggested explanation for an event, which can be tested. Hypotheses, or tentative explanations, are generally produced within the context of a **scientific theory**. A scientific theory is a generally accepted, thoroughly tested and confirmed explanation for a set of observations or phenomena. Scientific theory is the foundation of scientific knowledge. In addition, in many scientific disciplines (less so in biology) there are **scientific laws**, often expressed in mathematical formulas, which describe how elements of nature will behave under certain specific conditions. There is not an evolution of hypotheses through theories to laws as if they represented some increase in certainty about the world. Hypotheses are the day-to-day material that scientists work with and they are developed within the context of theories. Laws are concise descriptions of parts of the world that are amenable to formulaic or mathematical description.

## Natural Sciences

What would you expect to see in a museum of natural sciences? Frogs? Plants? Dinosaur skeletons? Exhibits about how the brain functions? A planetarium? Gems and minerals? Or maybe all of the above? Science includes such diverse fields as astronomy, biology, computer sciences, geology, logic, physics, chemistry, and mathematics. However, those fields of science related to the physical world and its phenomena and processes are considered **natural sciences**. Thus, a museum of natural sciences might contain any of the items listed above.

## Scientific Inquiry

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

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

**Deductive reasoning** or deduction is the type of logic used in hypothesis-based science (OpenStax College, 2013). In deductive reasoning, the pattern of thinking moves in the opposite direction as compared to inductive reasoning. Deductive reasoning is a form of logical thinking that uses a general principle or law to forecast specific results. From those general principles, a scientist can extrapolate and predict the specific results that would be valid as long as the general principles are valid. For example, a prediction would be that if the climate is becoming warmer in a region, the distribution of plants and animals should change. Comparisons have been made between distributions in the past and the present, and the many changes that have been found are consistent with a warming climate. Finding the change in distribution is evidence that the climate change conclusion is a valid one.

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

## Hypothesis Testing

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

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

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

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

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

Each experiment will have one or more variables and one or more controls (OpenStax College, 2013). A **variable** is any part of the experiment that can vary or change during the experiment. A **control** is a part of the experiment that does not change. Look for the variables and controls in the example that follows. As a simple example, an experiment might be conducted to test the hypothesis that phosphate limits the growth of algae in freshwater ponds. A series of artificial ponds are filled with water and half of them are treated by adding phosphate each week, while the other half are treated by adding a salt that is known not to be used by algae. The variable here is the phosphate (or lack of phosphate), the experimental or treatment cases are the ponds with added phosphate and the control ponds are those with something inert added, such as the salt. Just adding something is also a control against the possibility that adding extra matter to the pond has an effect. If the treated ponds show lesser growth of algae, then we have found support for our hypothesis. If they do not, then we reject our hypothesis. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid (Figure 3.4). Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

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

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

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

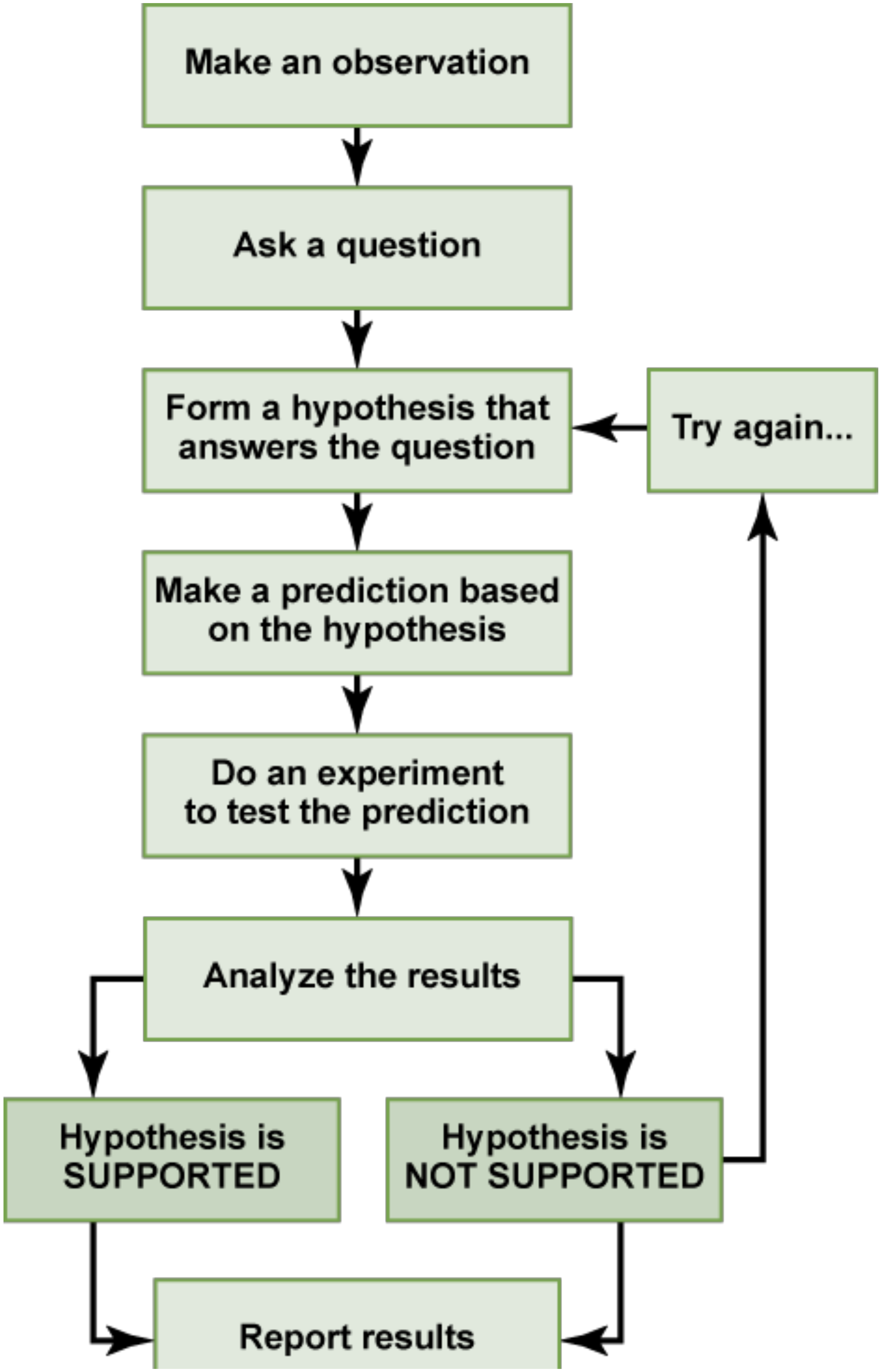
## Basic and Applied Science

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

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

In contrast, **applied science** or "technology," aims to use science to solve real-world problems, making it possible, for example, to improve a crop yield, find a cure for a particular disease, or save animals threatened by a natural disaster. In applied science, the problem is usually defined for the researcher.

Some individuals may perceive applied science as "useful" and basic science as "useless." A question these people might pose to a scientist advocating knowledge acquisition would be, "What for?" A careful look at the history of science, however, reveals that basic knowledge has resulted in many remarkable applications of great value. Many scientists think that a basic understanding of science is necessary before an application is developed; therefore, applied science relies on the results generated through basic science. Other scientists think that it is time to move on from basic science and instead to find solutions to actual problems. Both approaches are valid. It is true that


Make an observation
Ask a question
Form a hypothesis that answers the question
Try again...
Make a prediction based on the hypothesis
Do an experiment to test the prediction
Analyze the results
Hypothesis is SUPPORTED
Hypothesis is NOT SUPPORTED
Report results

there are problems that demand immediate attention; however, few solutions would be found without the help of the knowledge generated through basic science.

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

Another example of the link between basic and applied research is the Human Genome Project, a study in which each human chromosome was analyzed and mapped to determine the precise sequence of DNA subunits and the exact location of each gene. (The gene is the basic unit of heredity; an individual's complete collection of genes is his or her genome.) Other organisms have also been studied as part of this project to gain a better understanding of human chromosomes. The Human Genome Project (Figure 3.5) relied on basic research carried out with non-human organisms and, later, with the human genome. An important end goal eventually became using the data for applied research seeking cures for genetically related diseases.


FIGURE 3.5

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

### Reporting Scientific Work

Whether scientific research is basic science or applied science, scientists must share their findings for other researchers to expand and build upon their discoveries (OpenStax College, 2013). Communication and collaboration within and between sub disciplines of science are key to the advancement of knowledge in science. For this reason, an important aspect of a scientist's work is disseminating results and communicating with peers. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the limited few who are present. Instead, most scientists present their results in peer-reviewed articles that are published in scientific journals. **Peer-reviewed articles** are scientific papers that are reviewed, usually anonymously by a scientist's colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review helps to ensure that the research described in a scientific paper or grant proposal is original, significant, logical, and thorough. Grant proposals, which are requests for research funding, are also subject to peer review. Scientists publish their work so other scientists can reproduce their experiments under similar or different conditions to expand on the findings. The experimental results must be consistent with the findings of other scientists.

There are many journals and the popular press that do not use a peer-review system. A large number of online open-access journals, journals with articles available without cost, are now available many of which use rigorous peer-review systems, but some of which do not. Results of any studies published in these forums without peer review are not reliable and should not form the basis for other scientific work. In one exception, journals may allow a researcher to cite a personal communication from another researcher about unpublished results with the cited author's permission.

# 3.2 Resources

## Summary

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

## Lesson Review Questions

1. What is science?
2. Describe the process of scientific method.
3. What are inductive reasoning and deductive reasoning?
4. Describe the goals of basic and applied science.
5. Give one example of the link between basic and applied research.
6. What are peer-reviewed articles?
7. Explain the following terms: hypothesis, falsifiability, scientific law.

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## Supplementary Images

U.S. Fish and Wildlife Service Southeast Region. (2013). Service botanist Mara Alexander taking a water sample. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/File:Service_botanist_Mara_Alexander_taking_a_water_sample_(9666514088).jpg

# CHAPTER 4 Matter, Energy and Life

## Chapter Outline



FIGURE 4.1
This sage thrasher's diet, like that of almost all organisms, depends on photosynthesis.

### Learning Outcomes

After studying this chapter, you should be able to:

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

## 4.1 Matter

### Atoms, Molecules, Compounds

At its most fundamental level, life is made up of matter (OpenStax College, 2013). Matter occupies space and has mass. All matter is composed of elements, substances that cannot be broken down or transformed chemically into other substances. Each element is made of atoms, each with a constant number of protons and unique properties. A total of 118 elements have been defined; however, only 92 occur naturally, and fewer than 30 are found in living cells. The remaining 26 elements are unstable and, therefore, do not exist for very long or are theoretical and have yet to be detected. Each element is designated by its chemical symbol (such as H, N, O, C, and Na), and possesses unique properties. These unique properties allow elements to combine and to bond with each other in specific ways.

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

At the most basic level, all organisms are made of a combination of **elements**. They contain atoms that combine together to form **molecules**. In multicellular organisms, such as animals, molecules can interact to form cells that combine to form tissues, which make up organs. These combinations continue until entire multicellular organisms are formed. All atoms contain protons, electrons, and neutrons (Figure 4.2). The only exception is hydrogen (H), which is made of one proton and one electron. A **proton** is a positively charged particle that resides in the nucleus (the core of the atom) of an atom and has a mass of 1 and a charge of +1. An **electron** is a negatively charged particle that travels in the space around the nucleus. In other words, it resides outside of the nucleus. It has a negligible mass and has a charge of –1.

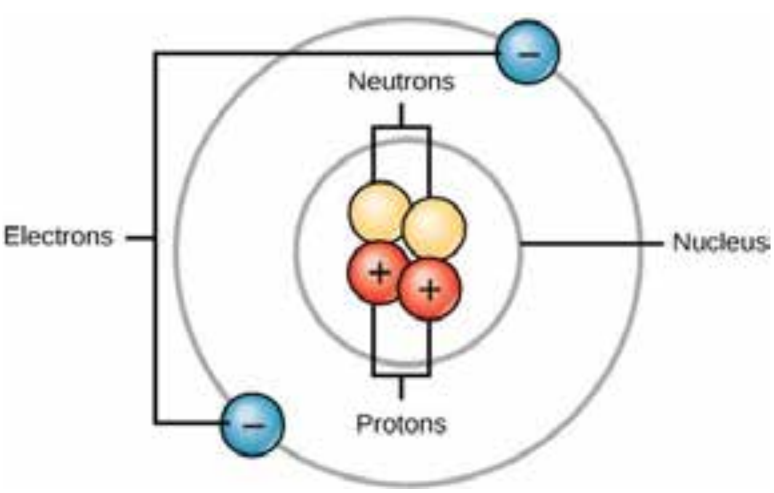



FIGURE 4.2
Atoms are made up of protons and neutrons located within the nucleus, and elec- trons surrounding the nucleus.

**Neutrons**, like protons, reside in the nucleus of an atom. They have a mass of 1 and no charge. The positive (protons) and negative (electrons) charges balance each other in a neutral atom, which has a net zero charge.

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

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

TABLE 4.1:

| **EVOLUTION IN ACTION** |
| --- |
| **Carbon dating**<br>Carbon-14 (14C) is a naturally occurring radioisotope that is created in the atmosphere by cosmic rays. This is a continuous process, so more 14C is always being created. As a living organism develops, the relative level of 14C in its body is equal to the concentration of 14C in the atmosphere. When an organism dies, it is no longer ingesting 14C, so the ratio will decline. 14C decays to 14N by a process called beta decay; it gives off energy in this slow process. After approximately 5,730 years, only one-half of the starting concentration of 14C will have been converted to 14N. The time it takes for half of the original concentration of an isotope to decay to its more stable form is called its half-life.<br>Because the half-life of 14C is long, it is used to age formerly living objects, such as fossils. Using the ratio of the 14C concentration found in an object to the amount of 14C detected in the atmosphere, the amount of the isotope that has not yet decayed can be determined. Based on this amount, the age of the fossil can be calculated to about 50,000 years (Figure 4.1). Isotopes with longer half-lives, such as potassium-40, are used to calculate the ages of older fossils. Through the use of carbon dating, scientists can reconstruct the ecology and biogeography of organisms living within the past 50,000 years. |
| <br>The age of remains that contain carbon and are less than about 50,000 years old, such as this pygmy mammoth, can be determined using carbon dating. (credit: Bill Faulkner/ NPS) |

## Chemical bonds

How elements interact with one another depends on how their electrons are arranged and how many openings for electrons exist at the outermost region where electrons are present in an atom. Electrons exist at energy levels that form shells around the nucleus. The closest shell can hold up to two electrons. The closest shell to the nucleus is always filled first, before any other shell can be filled. Hydrogen has one electron; therefore, it has only one spot occupied within the lowest shell. Helium has two electrons; therefore, it can completely fill the lowest shell with its two electrons. If you look at the periodic table, you will see that hydrogen and helium are the only two elements in the first row. This is because they only have electrons in their first shell. Hydrogen and helium are the only two elements that have the lowest shell and no other shells.

Not all elements have enough electrons to fill their outermost shells, but an atom is at its most stable when all of the electron positions in the outermost shell are filled. Because of these vacancies in the outermost shells, we see the formation of chemical bonds, or interactions between two or more of the same or different elements that result in the formation of molecules. To achieve greater stability, atoms will tend to completely fill their outer shells and will bond with other elements to accomplish this goal by sharing electrons, accepting electrons from another atom, or donating electrons to another atom. Because the outermost shells of the elements with low atomic numbers (up to calcium, with atomic number 20) can hold eight electrons, this is referred to as the octet rule. An element can donate, accept, or share electrons with other elements to fill its outer shell and satisfy the octet rule.

When an atom does not contain equal numbers of protons and electrons, it is called an **ion**. Because the number of electrons does not equal the number of protons, each ion has a net **charge**. Positive ions are formed by losing electrons and are called **cations**. Negative ions are formed by gaining electrons and are called **anions**. Elemental anionic names are changed to end in -ide. For example, sodium only has one electron in its outermost shell. It takes less energy for sodium to donate that one electron than it does to accept seven more electrons to fill the outer shell. If sodium loses an electron, it now has 11 protons and only 10 electrons, leaving it with an overall charge of +1. It is now called a sodium ion.

**Ionic** and **covalent bonds** are strong bonds or interactions that require a larger energy input to break apart. When an element donates an electron from its outer shell, as in the sodium atom example above, a positive ion is formed. The element accepting the electron is now negatively charged. Because positive and negative charges attract, these ions stay together and form an **ionic bond**, or a bond between ions. The elements bond together with the electron from one element staying predominantly with the other element.

Another type of strong chemical bond between two or more atoms is a **covalent bond**. These bonds form when an electron is shared between two elements and are the strongest and most common form of chemical bond in living organisms. Covalent bonds form between the elements that make up the biological molecules in our cells. Unlike ionic bonds, covalent bonds do not dissociate in water.

The hydrogen and oxygen atoms that combine to form water molecules are bound together by covalent bonds. The electron from the hydrogen atom divides its time between the outer shell of the hydrogen atom and the incomplete outer shell of the oxygen atom. To completely fill the outer shell of an oxygen atom, two electrons from two hydrogen atoms are needed, hence the subscript "2" in $H_2O$. The electrons are shared between the atoms, dividing their time between them to "fill" the outer shell of each. This sharing is a lower energy state for all of the atoms involved than if they existed without their outer shells filled.

When polar covalent bonds containing a hydrogen atom form, the hydrogen atom in that bond has a slightly positive charge. This is because the shared electron is pulled more strongly toward the other element and away from the hydrogen nucleus. Because the hydrogen atom is slightly positive ($\delta+$), it will be attracted to neighboring negative partial charges ($\delta-$). When this happens, a weak interaction occurs between the $\delta+$ charge of the hydrogen atom of one molecule and the $\delta-$ charge of the other molecule. This interaction is called a **hydrogen bond**. This type of bond is common; for example, the liquid nature of water is caused by the hydrogen bonds between water molecules. Hydrogen bonds give water the unique properties that sustain life. If it were not for hydrogen bonding, water would be a gas rather than a liquid at room temperature.

## TABLE 4.2:

| WATER IS CRUCIAL TO MAINTAINING LIFE |
| --- |
| Do you ever wonder why scientists spend time looking for water on other planets? It is because water is essential to life; even minute traces of it on another planet can indicate that life could or did exist on that planet. Water is one of the more abundant molecules in living cells and the one most critical to life as we know it. Approximately 60–70 percent of your body is made up of water. Without it, life simply would not exist.<br><br>• **WATER IS POLAR.** The hydrogen and oxygen atoms within water molecules form polar covalent bonds. The shared electrons spend more time associated with the oxygen atom than they do with hydrogen atoms. There is no overall charge to a water molecule, but there is a slight positive charge on each hydrogen atom and a slight negative charge on the oxygen atom. Because of these charges, the slightly positive hydrogen atoms repel each other and form the unique shape. Each water molecule attracts other water molecules because of the positive and negative charges in the different parts of the molecule. Water also attracts other polar molecules (such as sugars) that can dissolve in water and are referred to as hydrophilic ("water-loving").<br>• **WATER STABILIZES TEMPERATURE.** The hydrogen bonds in water allow it to absorb and release heat energy more slowly than many other substances. Temperature is a measure of the motion (kinetic energy) of molecules. As the motion increases, energy is higher and thus temperature is higher. Water absorbs a great deal of energy before its temperature rises. Increased energy disrupts the hydrogen bonds between water molecules. Because these bonds can be created and disrupted rapidly, water absorbs an increase in energy and temperature changes only minimally. This means that water moderates temperature changes within organisms and in their environments.<br>• **WATER IS AN EXCELLENT SOLVENT.** Because water is polar, with slight positive and negative charges, ionic compounds and polar molecules can readily dissolve in it. Water is, therefore, what is referred to as a solvent—a substance capable of dissolving another substance. The charged particles will form hydrogen bonds with a surrounding layer of water molecules.<br>• **WATER IS COHESIVE.** Have you ever filled up a glass of water to the very top and then slowly added a few more drops? Before it overflows, the water actually forms a dome-like shape above the rim of the glass. This water can stay above the glass because of the property of cohesion. In cohesion, water molecules are attracted to each other (because of hydrogen bonding), keeping the molecules together at the liquid-air (gas) interface, although there is no more room in the glass. Cohesion gives rise to surface tension, the capacity of a substance to withstand rupture when placed under tension or stress. When you drop a small scrap of paper onto a droplet of water, the paper floats on top of the water droplet, although the object is denser (heavier) than the water. This occurs because of the surface tension that is created by the water molecules. Cohesion and surface tension keep the water molecules intact and the item floating on the top. It is even possible to "float" a steel needle on top of a glass of water if you place it gently, without breaking the surface tension. These cohesive forces are also related to the water's property of adhesion, or the attraction between water molecules and other molecules. This is observed when water "climbs" up a straw placed in a glass of water. You will notice that the water appears to be higher on the sides of the straw than in the middle. This is because the water molecules are attracted to the straw and therefore adhere to it. Cohesive and adhesive forces are important for sustaining life. For example, because of these forces, water can flow up from the roots to the tops of plants to feed the plant. |

### Buffers, pH, Acids, and Bases

The pH of a solution is a measure of its **acidity** or **alkalinity**. The pH scale ranges from 0 to 14. A change of one unit on the pH scale represents a change in the concentration of hydrogen ions by a factor of 10, a change in two units represents a change in the concentration of hydrogen ions by a factor of 100. Thus, small changes in pH represent large changes in the concentrations of hydrogen ions. Pure water is neutral. It is neither acidic nor basic, and has a pH of 7.0. Anything below 7.0 (ranging from 0.0 to 6.9) is acidic, and anything above 7.0 (from 7.1 to 14.0) is alkaline. The blood in your veins is slightly alkaline (pH = 7.4). The environment in your stomach is highly acidic (pH = 1 to 2). Orange juice is mildly acidic (pH = approximately 3.5), whereas baking soda is basic (pH = 9.0). Acids are substances that provide hydrogen ions (H+) and lower pH, whereas bases provide hydroxide ions (OH–) and raise pH. The stronger the acid, the more readily it donates H+. For example, hydrochloric acid and lemon juice are very acidic and readily give up H+ when added to water. Conversely, bases are those substances that readily donate OH–. The OH– ions combine with H+ to produce water, which raises a substance's pH. Sodium hydroxide and many household cleaners are very alkaline and give up OH– rapidly when placed in water, thereby raising the pH.

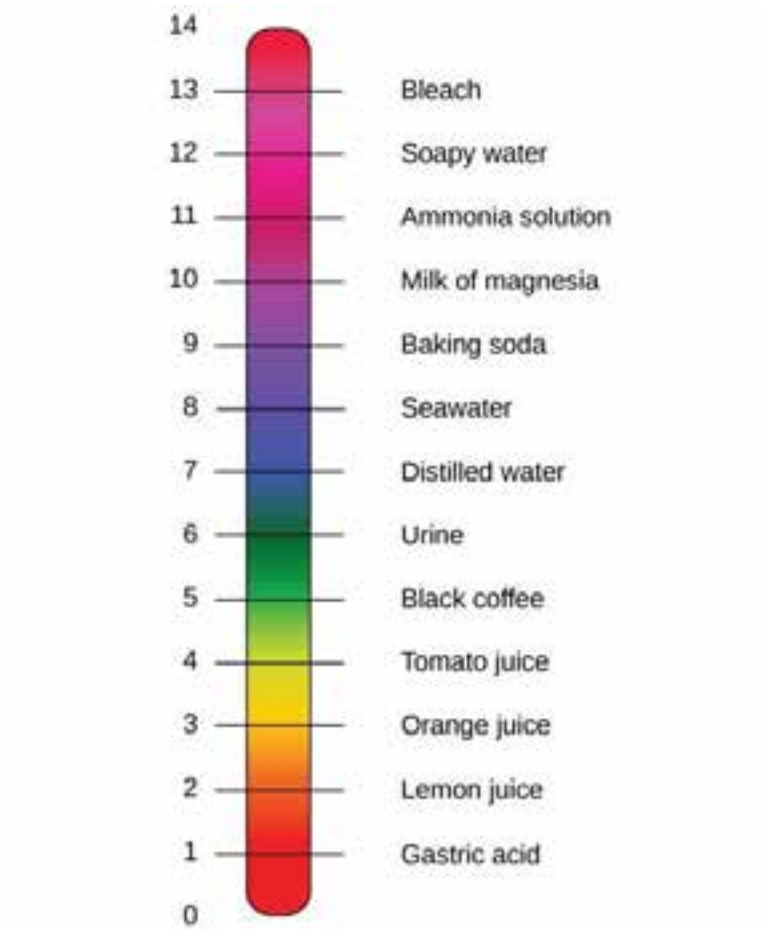



FIGURE 4.3

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

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

## Biological Molecules

The large molecules necessary for life that are built from smaller organic molecules are called **biological macromolecules**. There are four major classes of biological macromolecules (**carbohydrates**, **lipids**, **proteins**, and nucleic **acids**), and each is an important component of the cell and performs a wide array of functions. Combined, these molecules make up the majority of a cell's mass. Biological macromolecules are organic, meaning that they contain carbon. In addition, they may contain hydrogen, oxygen, nitrogen, phosphorus, sulfur, and additional minor elements.

### Carbon

It is often said that life is "carbon-based." This means that carbon atoms, bonded to other **carbon** atoms or other elements, form the fundamental components of many, if not most, of the molecules found uniquely in living things. Other elements play important roles in biological molecules, but carbon certainly qualifies as the "foundation" element for molecules in living things. It is the bonding properties of carbon atoms that are responsible for its important role.

*Carbon bonding*

Carbon contains four electrons in its outer shell. Therefore, it can form four covalent bonds with other atoms or molecules. The simplest organic carbon molecule is methane (CH4), in which four hydrogen atoms bind to a carbon atom (Figure 4.4).

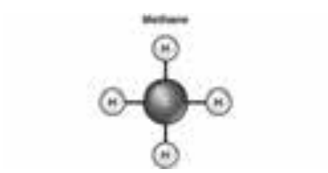


FIGURE 4.4
Carbon can form four covalent bonds to create an organic molecule. The simplest carbon molecule is methane (CH4), depicted here

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

**Proteins** are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. They are all polymers of amino acids, arranged in a linear sequence. The functions of proteins are very diverse because there are 20 different chemically distinct amino acids that form long chains, and the amino acids can be in any order. For example, proteins can function as enzymes or hormones.

**Enzymes**, which are produced by living cells, are catalysts in biochemical reactions (like digestion) and are usually proteins. Each enzyme is specific for the substrate (a reactant that binds to an enzyme) upon which it acts. Enzymes can function to break molecular bonds, to rearrange bonds, or to form new bonds.

**Nucleic acids** are key macromolecules in the continuity of life. They carry the genetic blueprint of a cell and carry instructions for the functioning of the cell. The two main types of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the genetic material found in all living organisms, ranging from single-celled bacteria to multicellular mammals. The other type of nucleic acid, RNA, is mostly involved in protein synthesis. The DNA molecules never leave the nucleus, but instead use an RNA intermediary to communicate with the rest of the cell. Other types of RNA are also involved in protein synthesis and its regulation. DNA and RNA are made up of monomers known as nucleotides. The nucleotides combine with each other to form a polynucleotide, DNA or RNA. Each nucleotide is made up of three components: a nitrogenous base, a pentose (five-carbon) sugar, and a phosphate group. Each nitrogenous base in a nucleotide is attached to a sugar molecule, which is attached to a phosphate group. DNA has a double-helical structure (Figure 4.5).

FIGURE 4.5

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

It is composed of two strands, or polymers, of nucleotides. The strands are formed with bonds between phosphate and sugar groups of adjacent nucleotides. The strands are bonded to each other at their bases with hydrogen bonds, and the strands coil about each other along their length, hence the "double helix" description, which means a double spiral. The alternating sugar and phosphate groups lie on the outside of each strand, forming the backbone of the DNA. The nitrogenous bases are stacked in the interior, like the steps of a staircase, and these bases pair; the pairs are bound to each other by hydrogen bonds. The bases pair in such a way that the distance between the backbones of the two strands is the same all along the molecule.

# 4.2 Energy

Virtually every task performed by living organisms requires energy. Energy is needed to perform heavy labor and exercise, but humans also use energy while thinking, and even during sleep. In fact, the living cells of every organism constantly use energy. Nutrients and other molecules are imported into the cell, metabolized (broken down) and possibly synthesized into new molecules, modified if needed, transported around the cell, and possibly distributed to the entire organism. For example, the large proteins that make up muscles are built from smaller molecules imported from dietary amino acids. Complex carbohydrates are broken down into simple sugars that the cell uses for energy. Just as energy is required to both build and demolish a building, energy is required for the synthesis and breakdown of molecules as well as the transport of molecules into and out of cells. In addition, processes such as ingesting and breaking down pathogenic bacteria and viruses, exporting wastes and toxins, and movement of the cell require energy. From where, and in what form, does this energy come? How do living cells obtain energy, and how do they use it? This section will discuss different forms of energy and the physical laws that govern energy transfer.

Scientists use the term bioenergetics to describe the concept of energy flow through living systems, such as cells. Cellular processes such as the building and breaking down of complex molecules occur through stepwise chemical reactions. Some of these chemical reactions are spontaneous and release energy, whereas others require energy to proceed. Just as living things must continually consume food to replenish their energy supplies, cells must continually produce more energy to replenish that used by the many energy-requiring chemical reactions that constantly take place. Together, all of the chemical reactions that take place inside cells, including those that consume or generate energy, are referred to as the cell's **metabolism**.

## Energy

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

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

### Thermodynamics

The first law of thermodynamics states that the total amount of energy in the universe is constant and conserved. In other words, there has always been, and always will be, exactly the same amount of energy in the universe. Energy exists in many different forms. According to the first law of thermodynamics, energy may be transferred from place to place or transformed into different forms, but it cannot be created or destroyed. The transfers and transformations of energy take place around us all the time. Light bulbs transform electrical energy into light and heat energy. Gas stoves transform chemical energy from natural gas into heat energy. Plants perform one of the most biologically useful energy transformations on earth: that of converting the energy of sunlight to chemical energy stored within organic molecules (Figure 4.7).

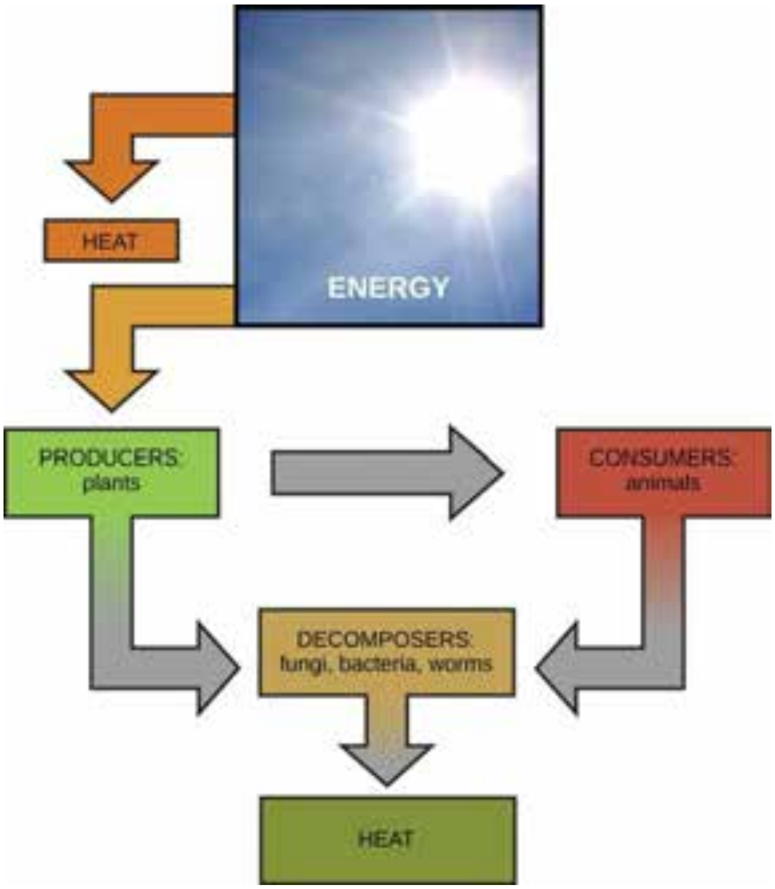



FIGURE 4.6
Ultimately, most life forms get their energy from the sun. Plants use photosynthesis to capture sunlight, and herbivores eat the plants to obtain energy. Carnivores eat the herbivores, and eventual decomposition of plant and animal material contributes to the nutrient pool.

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

FIGURE 4.7
Shown are some examples of energy transferred and transformed from one system to another and from one form to another. The food we consume provides our cells with the energy required to carry out bodily functions, just as light energy provides plants with the means to create the chemical energy they need. (credit "ice cream": modification of work by D. Sharon Pruitt; credit "kids": modification of work by Max from Providence; credit "leaf": modification of work by Cory Zanker)

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

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

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

**Potential and Kinetic Energy**

When an object is in motion, there is energy associated with that object. Think of a wrecking ball. Even a slow-moving wrecking ball can do a great deal of damage to other objects. Energy associated with objects in motion is called **kinetic energy**. A speeding bullet, a walking person, and the rapid movement of molecules in the air (which produces heat) all have kinetic energy. Now what if that same motionless wrecking ball is lifted two stories above ground with a crane? If the suspended wrecking ball is unmoving, is there energy associated with it? The answer is yes. The energy that was required to lift the wrecking ball did not disappear, but is now stored in the wrecking ball by virtue of its position and the force of gravity acting on it. This type of energy is called **potential energy** (Figure 4.8). If the ball were to fall, the potential energy would be transformed into kinetic energy until all of the potential energy was exhausted when the ball rested on the ground. Wrecking balls also swing like a pendulum; through the swing, there is a constant change of potential energy (highest at the top of the swing) to kinetic energy (highest at the bottom of the swing). Other examples of potential energy include the energy of water held behind a dam or a person about to skydive out of an airplane.

FIGURE 4.8
Still water has potential energy; moving water, such as in a waterfall or a rapidly flowing river, has kinetic energy. (credit "dam": modification of work by "Pascal"/Flickr; credit "waterfall": modification of work by Frank Gualtieri)

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

## 4.3 A Cell is the Smallest Unit of Life

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

A cell is the smallest unit of a living thing. A living thing, like you, is called an organism. Thus, cells are the basic building blocks of all organisms. In multicellular organisms, several cells of one particular kind interconnect with each other and performed shared functions to form tissues (for example, muscle tissue, connective tissue, and nervous tissue), several tissues combine to form an organ (for example, stomach, heart, or brain), and several organs make up an organ system (such as the digestive system, circulatory system, or nervous system). Several systems functioning together form an organism (such as an elephant, for example).

### Cell Theory

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

By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the unified cell theory, which states that all living things are composed of one or more cells, that the cell is the basic unit of life, and that all new cells arise from existing cells. These principles still stand today.

There are many types of cells, and all are grouped into one of two broad categories: prokaryotic and eukaryotic. Animal cells, plant cells, fungal cells, and protist cells are classified as eukaryotic, whereas bacteria and archaea cells are classified as prokaryotic.

### Components of Prokaryotic Cells

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

A prokaryotic cell is a simple, single-celled (unicellular) organism that lacks a nucleus, or any other membrane-bound organelle. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in the central part of the cell: a darkened region called the nucleoid (Figure 4.9).

Unlike Archaea and eukaryotes, bacteria have a cell wall made of peptidoglycan, comprised of sugars and amino acids, and many have a polysaccharide capsule. The cell wall acts as an extra layer of protection, helps the cell

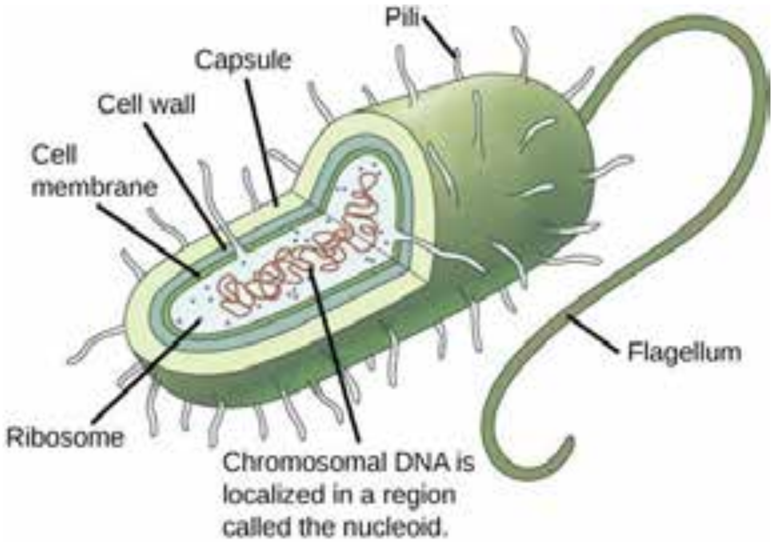



FIGURE 4.9
This figure shows the generalized structure of a prokaryotic cell.

maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili are used to exchange genetic material during a type of reproduction called conjugation. Fimbriae are protein appendages used by bacteria to attach to other cells.

## Eukaryotic Cells

In nature, the relationship between form and function is apparent at all levels, including the level of the cell, and this will become clear as we explore eukaryotic cells. The principle "form follows function" is found in many contexts. For example, birds and fish have streamlined bodies that allow them to move quickly through the medium in which they live, be it air or water. It means that, in general, one can deduce the function of a structure by looking at its form, because the two are matched. A eukaryotic cell is a cell that has a membrane-bound nucleus and other membrane-bound compartments or sacs, called organelles, which have specialized functions. The word eukaryotic means "true kernel" or "true nucleus," alluding to the presence of the membrane-bound nucleus in these cells. The word "organelle" means "little organ," and, as already mentioned, organelles have specialized cellular functions, just as the organs of your body have specialized functions.

### Cell Size

At 0.1–5.0 $\mu$m in diameter, prokaryotic cells are significantly smaller than eukaryotic cells, which have diameters ranging from 10–100 $\mu$m (Figure 4.10). The small size of prokaryotes allows ions and organic molecules that enter them to quickly spread to other parts of the cell. Similarly, any wastes produced within a prokaryotic cell can quickly move out. However, larger eukaryotic cells have evolved different structural adaptations to enhance cellular transport. Indeed, the large size of these cells would not be possible without these adaptations. In general, cell size is limited because volume increases much more quickly than does cell surface area. As a cell becomes larger, it becomes more and more difficult for the cell to acquire sufficient materials to support the processes inside the cell, because the relative size of the surface area through which materials must be transported declines.

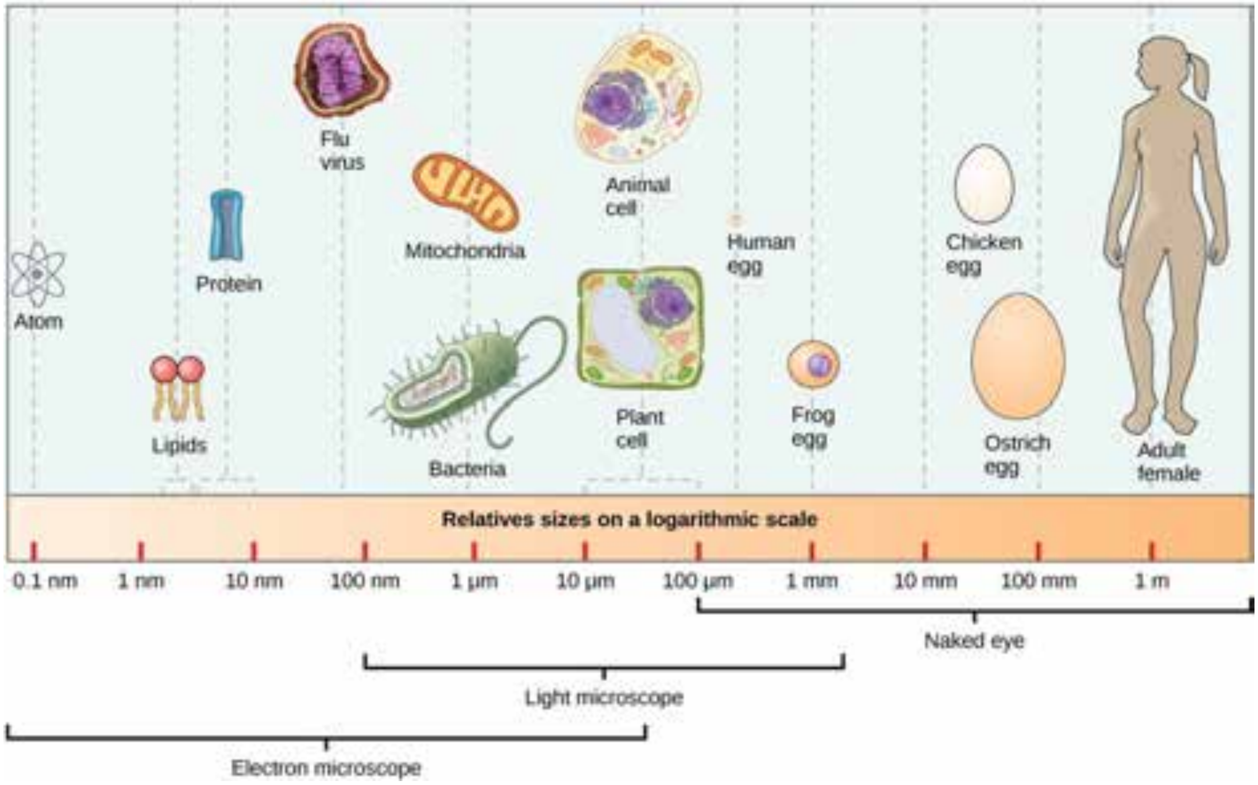


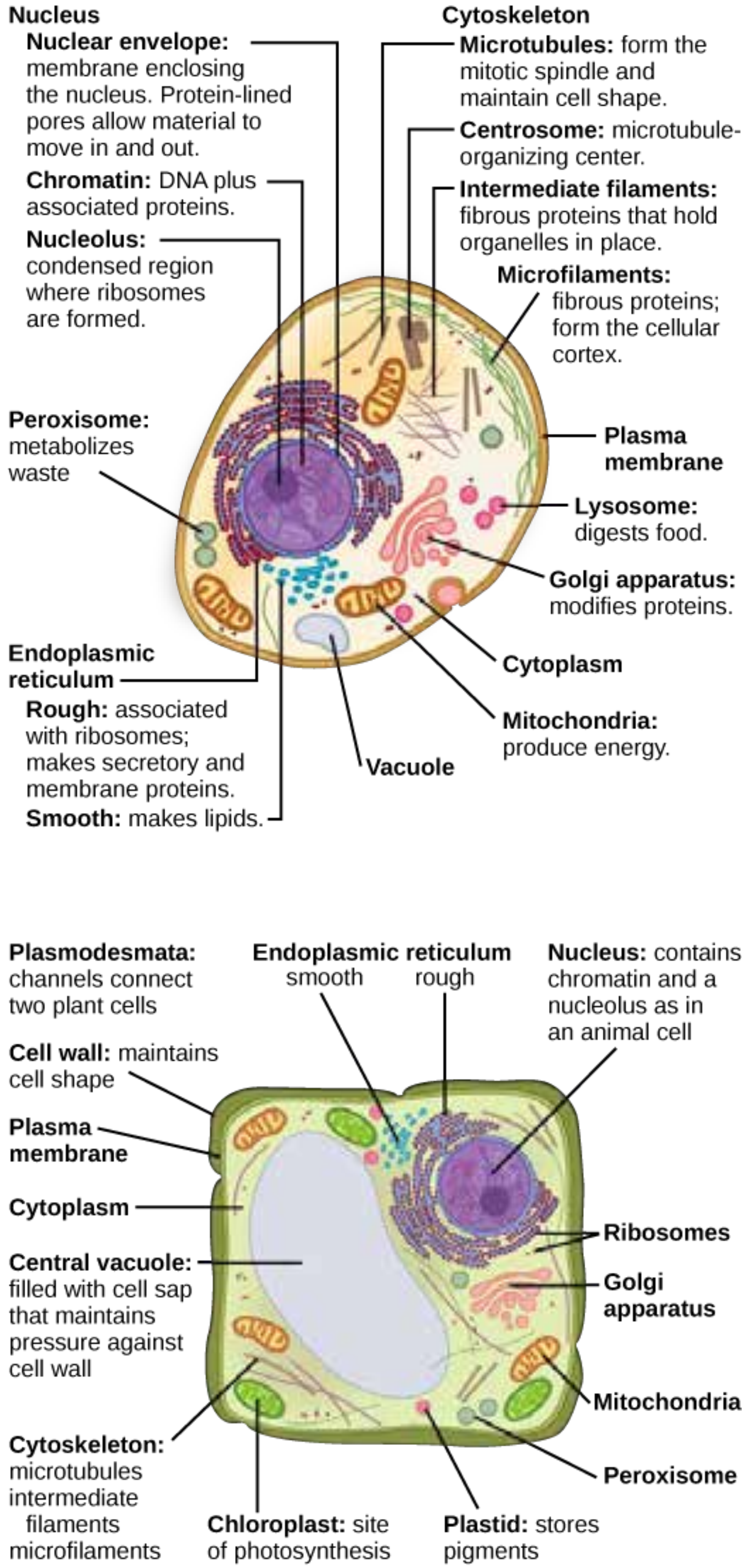

FIGURE 4.10
This figure shows the relative sizes of different kinds of cells and cellular components. An adult human is shown for comparison.

### Animal Cells versus Plant Cells

Despite their fundamental similarities, there are some striking differences between animal and plant cells. Animal cells have centrioles, centrosomes (discussed under the cytoskeleton), and lysosomes, whereas plant cells do not. Plant cells have a cell wall, chloroplasts, plasmodesmata, and plastids used for storage, and a large central vacuole, whereas animal cells do not.

### The Cell Wall

In Figure below, the diagram of a plant cell, you see a structure external to the plasma membrane called the cell wall. The cell wall is a rigid covering that protects the cell, provides structural support, and gives shape to the cell. Fungal and protist cells also have cell walls. While the chief component of prokaryotic cell walls is peptidoglycan, the major organic molecule in the plant cell wall is cellulose, a polysaccharide made up of long, straight chains of glucose units. When nutritional information refers to dietary fiber, it is referring to the cellulose content of food.




*The figure shows a typical animal cell (top) and a typical plant cell (bottom).*

### Chloroplasts

Like mitochondria, chloroplasts also have their own DNA and ribosomes. Chloroplasts function in photosynthesis and can be found in eukaryotic cells such as plants and algae. In photosynthesis, carbon dioxide, water, and light energy are used to make glucose and oxygen. This is the major difference between plants and animals: Plants (autotrophs) are able to make their own food, like glucose, whereas animals (heterotrophs) must rely on other organisms for their organic compounds or food source. Like mitochondria, chloroplasts have outer and inner membranes, but within the space enclosed by a chloroplast's inner membrane is a set of interconnected and stacked, fluid-filled membrane sacs called thylakoids (Figure 4.11).

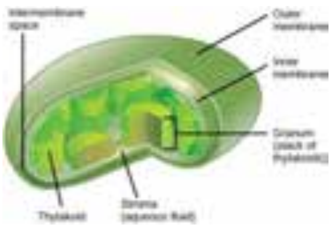


FIGURE 4.11
This simplified diagram of a chloroplast shows the outer membrane, inner membrane, thylakoids, grana, and stroma.

Each stack of thylakoids is called a granum (plural = grana). The fluid enclosed by the inner membrane and surrounding the grana is called the stroma.

# 4.4 Energy Enters Ecosystems Through Photosynthesis

All living organisms on earth consist of one or more cells (CK12, 2015a, 2015b). Each cell runs on the chemical energy found mainly in carbohydrate molecules (food), and the majority of these molecules are produced by one process: photosynthesis. Through photosynthesis, certain organisms convert solar energy (sunlight) into chemical energy, which is then used to build carbohydrate molecules. The energy used to hold these molecules together is released when an organism breaks down food. Cells then use this energy to perform work, such as cellular respiration. The energy that is harnessed from photosynthesis enters the ecosystems of our planet continuously and is transferred from one organism to another. Therefore, directly or indirectly, the process of photosynthesis provides most of the energy required by living things on earth. Photosynthesis also results in the release of oxygen into the atmosphere. In short, to eat and breathe, humans depend almost entirely on the organisms that carry out photosynthesis.

## Solar Dependence and Food Production

Some organisms can carry out photosynthesis, whereas others cannot. An **autotroph** is an organism that can produce its own food. The Greek roots of the word autotroph mean "self" (auto) "feeder" (troph). Plants are the best-known autotrophs, but others exist, including certain types of bacteria and algae (Figure 4.12). Oceanic algae contribute enormous quantities of food and oxygen to global food chains. Plants are also **photoautotrophs**, a type of autotroph that uses sunlight and carbon from carbon dioxide to synthesize chemical energy in the form of carbohydrates. All organisms carrying out photosynthesis require sunlight.


FIGURE 4.12

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

Heterotrophs are organisms incapable of photosynthesis that must therefore obtain energy and carbon from food by consuming other organisms. The Greek roots of the word *heterotroph* mean "other" (*hetero*) "feeder" (*troph*), meaning that their food comes from other organisms. Even if the food organism is another animal, this food traces its origins back to autotrophs and the process of photosynthesis. Humans are heterotrophs, as are all animals. Heterotrophs depend on autotrophs, either directly or indirectly. Deer and wolves are heterotrophs. A deer obtains energy by eating plants. A wolf eating a deer obtains energy that originally came from the plants eaten by that deer.

The energy in the plant came from photosynthesis, and therefore it is the only autotroph in this example (Figure 4.13). Using this reasoning, all food eaten by humans also links back to autotrophs that carry out photosynthesis.

FIGURE 4.13
The energy stored in carbohydrate molecules from photosynthesis passes through the food chain. The predator that eats these deer is getting energy that originated in the photosynthetic vegetation that the deer consumed. (credit: Steve VanRiper, U.S. Fish and Wildlife Service)

## Main Structures and Summary of Photosynthesis

Photosynthesis requires sunlight, carbon dioxide, and water as starting reactants (Figure4.14). After the process is complete, photosynthesis releases oxygen and produces carbohydrate molecules, most commonly glucose. These sugar molecules contain the energy that living things need to survive.

The complex reactions of photosynthesis can be summarized by the chemical equation shown in Figure4.15

Although the equation looks simple, the many steps that take place during photosynthesis are actually quite complex, as in the way that the reaction summarizing cellular respiration represented many individual reactions. In plants, photosynthesis takes place primarily in leaves, which consist of many layers of cells and have differentiated top and bottom sides.

Photosynthesis takes place inside an organelle called a **chloroplast**. Chloroplasts have a double (inner and outer) membrane. Within the chloroplast is a third membrane that forms stacked, disc-shaped structures called **thylakoids**. Embedded in the thylakoid membrane are molecules of **chlorophyll**, a pigment (a molecule that absorbs light) through which the entire process of photosynthesis begins.

## The Two Parts of Photosynthesis

Photosynthesis takes place in two stages: **the light-dependent reactions** and the **Calvin cycle.** In the light-dependent reactions chlorophyll absorbs energy from sunlight and then converts it into chemical energy with the use of water. The light-dependent reactions release **oxygen** from the hydrolysis of water as a byproduct. In the Calvin cycle, the chemical energy derived from the light-dependent reactions drives both the capture of carbon in **carbon dioxide** molecules and the subsequent assembly of sugar molecules. The two reactions use carrier molecules to transport the energy from one to the other. The carriers that move energy from the light-dependent reactions to the Calvin cycle reactions can be thought of as "full" because they bring energy. After the energy is released, the "empty" energy carriers return to the light-dependent reactions to obtain more energy.

Heterotrophs are organisms incapable of photosynthesis that must therefore obtain energy and carbon from food by consuming other organisms. Humans are heterotrophs, as are all animals. Heterotrophs depend on autotrophs, either

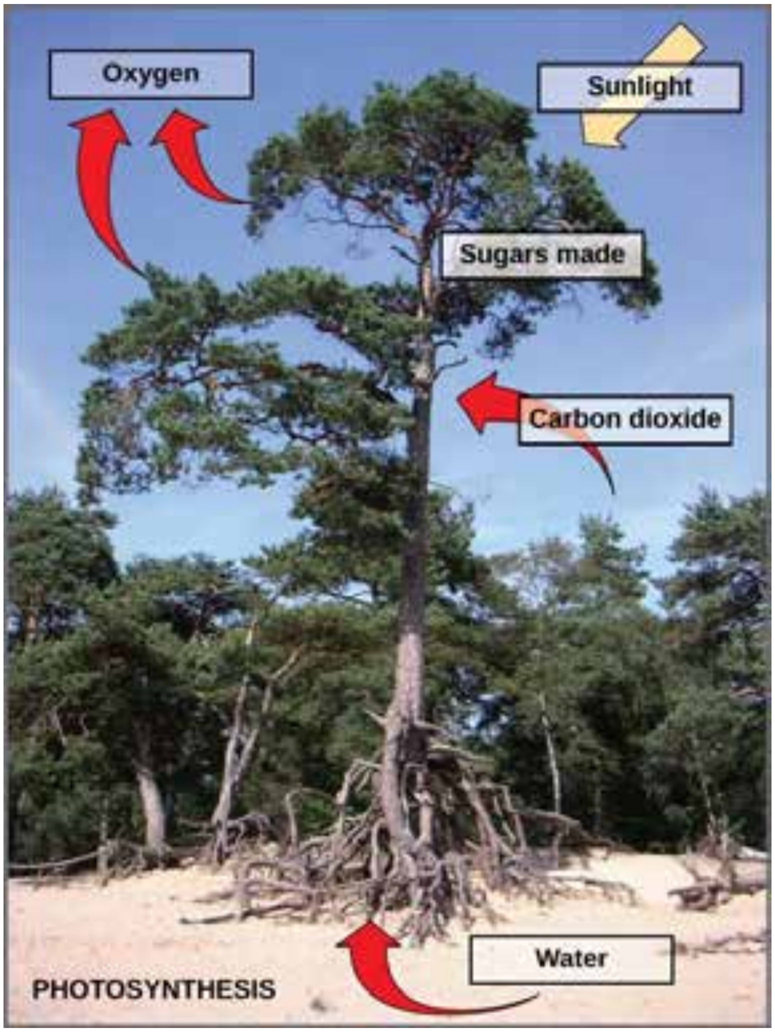



FIGURE 4.14
Photosynthesis uses solar energy, carbon dioxide, and water to release oxygen and to produce energy-storing sugar molecules.

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

FIGURE 4.15
This equation means that six molecules of carbon dioxide (CO2) combine with six molecules of water (H2O) in the presence of sunlight. This produces one molecule of glucose (C6H12O6) and six molecules of oxygen (O2).

directly or indirectly. Using this reasoning, all food eaten by humans also links back to autotrophs that carry out photosynthesis.

## Generating an Energy Carrier: ATP

Photosynthesis begins with the light reactions. It is during these reactions that the energy from sunlight is absorbed by the pigment chlorophyll in the thylakoid membranes of the chloroplast. The energy is then temporarily transferred to two molecules, ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate), which are used in the second stage of photosynthesis. The energy that these molecules carry is stored in a bond that holds a single atom to the molecule. For ATP, it is a phosphate atom, and for NADPH, it is a hydrogen atom. During the light reactions, water is used and oxygen is produced. When these molecules release energy into the Calvin cycle, they each lose atoms to become the lower-energy molecules ADP and NADP+.

## The Calvin cycle

After the energy from the sun is converted and packaged into ATP and NADPH, the cell has the fuel needed to build food in the form of **carbohydrate molecules**. The carbohydrate molecules made will have a backbone of carbon atoms. The carbon atoms used to build carbohydrate molecules comes from **carbon dioxide**, the gas that animals exhale with each breath. The Calvin cycle is the term used for the reactions of photosynthesis that use the energy stored by the light dependent reactions to form glucose and other carbohydrate molecules. In plants, carbon dioxide ($CO_2$) enters the chloroplast through the stomata and diffuses into the stroma of the chloroplast—the site of the Calvin cycle reactions where sugar is synthesized. The reactions are named after the scientist who discovered them, and reference the fact that the reactions function as a cycle.

## The Energy Cycle

Living things access energy by breaking down carbohydrate molecules. However, if plants make carbohydrate molecules, why would they need to break them down? Carbohydrates are storage molecules for energy in all living things. Although energy can be stored in molecules like ATP, carbohydrates are much more stable and efficient reservoirs for chemical energy. Photosynthetic organisms also carry out the reactions of respiration to harvest the energy that they have stored in carbohydrates, for example, plants have mitochondria in addition to chloroplasts.

You may have noticed that the overall reaction for photosynthesis

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

is the reverse of the overall reaction for cellular respiration:

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

Photosynthesis produces **oxygen** as a byproduct, and respiration produces **carbon dioxide** as a byproduct. In nature, there is no such thing as waste. Every single atom of matter is conserved, recycling indefinitely. Substances change form or move from one type of molecule to another, but never disappear. $CO_2$ is no more a form of waste produced by respiration than oxygen is a waste product of photosynthesis. Both are byproducts of reactions that move on to other reactions. Photosynthesis absorbs energy to build carbohydrates in chloroplasts, and aerobic cellular respiration releases energy by using oxygen to break down carbohydrates. Photosynthesis and cellular respiration function in a biological cycle, allowing organisms to access life-sustaining energy that originates millions of miles away in a star.

# 4.5 Resources

## Summary

Matter is anything that occupies space and has mass. It is made up of atoms of different elements. Elements that occur naturally have unique qualities that allow them to combine in various ways to create compounds or molecules. Atoms, which consist of protons, neutrons, and electrons, are the smallest units of an element that retain all of the properties of that element. Electrons can be donated or shared between atoms to create bonds, including ionic, covalent, and hydrogen bonds. The pH of a solution is a measure of the concentration of hydrogen ions in the solution. Living things are carbon-based because carbon plays such a prominent role in the chemistry of living things. A cell is the smallest unit of life. Most cells are so small that they cannot be viewed with the naked eye. The unified cell theory states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells. Each cell runs on the chemical energy found mainly in carbohydrate molecules (food), and the majority of these molecules are produced by one process: photosynthesis. Through photosynthesis, certain organisms convert solar energy (sunlight) into chemical energy, which is then used to build carbohydrate molecules. Directly or indirectly, the process of photosynthesis provides most of the energy required by living things on earth. Photosynthesis also results in the release of oxygen into the atmosphere. In short, to eat and breathe, humans depend almost entirely on the organisms that carry out photosynthesis.

Review Questions

1. What is matter?
2. What are elements?
3. Describe the interrelationship between protons, neutrons, and electrons, and the ways in which electrons can be donated or shared between atoms.
4. What is energy? Describe the two major types of energy.
5.Why is it often said that life is “carbon-based”?
6. Describe the roles of cells in organisms.
7.What is the cell theory?
8. Name examples of prokaryotic and eukaryotic organisms.
9. How are photosynthesis and cellular respiration complementary processes?
10. Why are carnivores, such as lions, dependent on photosynthesis to survive?

## 4.6 References

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# CHAPTER 5 Evolution

## Chapter Outline



FIGURE 5.1

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

### Learning Outcomes

After studying this chapter, you should be able to:

- Explain how Darwin's theory of evolution differed from the current view at the time
- Describe how the present-day theory of evolution was developed
- Describe the four basic causes of evolution
- Describe the definition of species and how species are identified as different

## 5.1 Discovering How Populations Change

All species of living organisms—from the bacteria on our skin, to the trees in our yards, to the birds outside—evolved at some point from a different species (OpenStax College, 2013). Although it may seem that living things today stay much the same from generation to generation, that is not the case: evolution is ongoing. Evolution is the process through which the characteristics of species change and through which new species arise.

The theory of evolution is the **unifying theory of biology**, meaning it is the framework within which biologists ask questions about the living world. Its power is that it provides direction for predictions about living things that are borne out in experiment after experiment.

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

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

In the early nineteenth century, Jean-Baptiste Lamarck published a book that detailed a mechanism for evolutionary change that is now referred to as inheritance of acquired characteristics. In Lamarck's theory, modifications in an individual caused by its environment, or the use or disuse of a structure during its lifetime, could be inherited by its offspring and, thus, bring about change in a species. While this mechanism for evolutionary change as described by Lamarck was discredited, Lamarck's ideas were an important influence on evolutionary thought. The inscription on the statue of Lamarck that stands at the gates of the Jardin des Plantes in Paris describes him as the "founder of the doctrine of evolution."

### Charles Darwin and Natural Selection

The actual mechanism for evolution was independently conceived of and described by two naturalists, Charles Darwin and Alfred Russell Wallace, in the mid-nineteenth century. Importantly, each spent time exploring the natural world on expeditions to the tropics. From 1831 to 1836, Darwin traveled around the world on *H.M.S. Beagle*, visiting South America, Australia, and the southern tip of Africa. Wallace traveled to Brazil to collect insects in the Amazon rainforest from 1848 to 1852 and to the Malay Archipelago from 1854 to 1862. Darwin's journey, like Wallace's later journeys in the Malay Archipelago, included stops at several island chains, the last being the Galápagos Islands (west of Ecuador). On these islands, Darwin observed species of organisms on different islands that were clearly similar, yet had distinct differences. For example, the ground finches inhabiting the Galápagos Islands comprised several species that each had a unique beak shape (Figure 5.2). He observed both that these finches closely resembled another finch species on the mainland of South America and that the group of species in the Galápagos formed a graded series of beak sizes and shapes, with very small differences between the most similar. Darwin imagined that the island species might be all species modified from one original mainland species. In 1860, he wrote, "Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends."

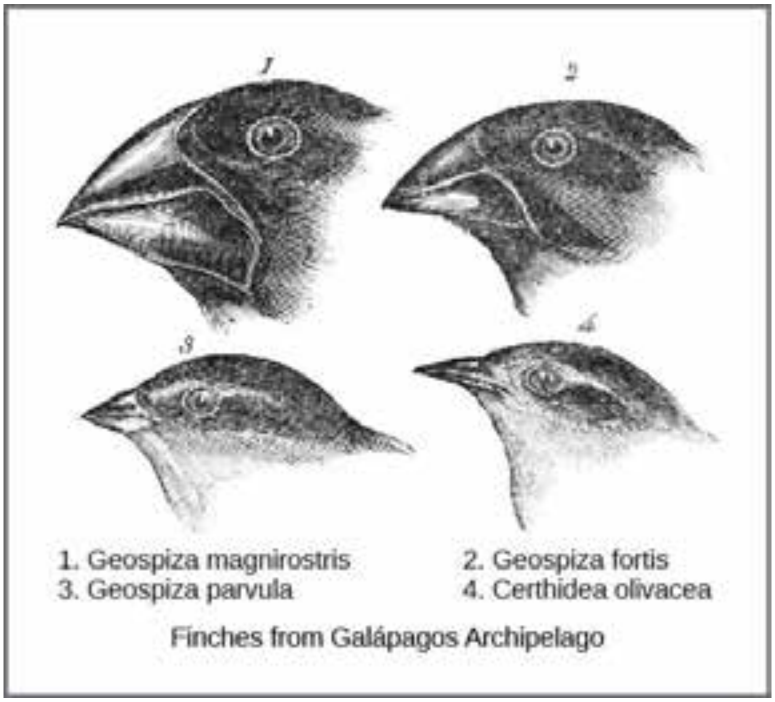


FIGURE 5.2
Darwin observed that beak shape varies among finch species. He postulated that the beak of an ancestral species had adapted over time to equip the finches to acquire different food sources. This illustration shows the beak shapes for four species of ground finch: 1.*Geospiza magnirostris* (the large ground finch), 2. G. *fortis* (the medium ground finch), 3. G. *parvula* (the small tree finch), and 4. *Certhidea olivacea* (the green-warbler finch).

Papers by Darwin and Wallace (Figure 5.3) presenting the idea of natural selection were read together in 1858 before the Linnaean Society in London. The following year Darwin's book, *On the Origin of Species*, was published, which outlined in considerable detail his arguments for evolution by natural selection.


FIGURE 5.3
(a) Charles Darwin and (b) Alfred Wallace wrote scientific papers on natural selection that were presented together before the Linnean Society in 1858.

Demonstrations of evolution by natural selection can be time consuming. One of the best demonstrations has been in the very birds that helped to inspire the theory, the Galápagos finches. Peter and Rosemary Grant and their colleagues have studied Galápagos finch populations every year since 1976 and have provided important demonstrations of the operation of natural selection. The Grants found changes from one generation to the next in the beak shapes of the medium ground finches on the Galápagos island of Daphne Major. The medium ground finch feeds on seeds. The birds have inherited variation in the bill shape with some individuals having wide, deep bills and others having thinner bills. Large-billed birds feed more efficiently on large, hard seeds, whereas smaller billed birds feed more efficiently on small, soft seeds. During 1977, a drought period altered vegetation on the island. After this period, the number of seeds declined dramatically: the decline in small, soft seeds was greater than the decline in large, hard seeds. The large-billed birds were able to survive better than the small-billed birds the following year. The year following the drought when the Grants measured beak sizes in the much-reduced population, they found that the average bill size was larger (Figure 5.4). This was clear evidence for natural selection (differences in survival) of bill size caused by the availability of seeds. The Grants had studied the inheritance of bill sizes and knew that the surviving large-billed birds would tend to produce offspring with larger bills, so the selection would lead to evolution of bill size. Subsequent studies by the Grants have demonstrated selection on and evolution of bill size in this species in response to changing conditions on the island. The evolution has occurred both to larger bills, as in this case, and to smaller bills when large seeds became rare.

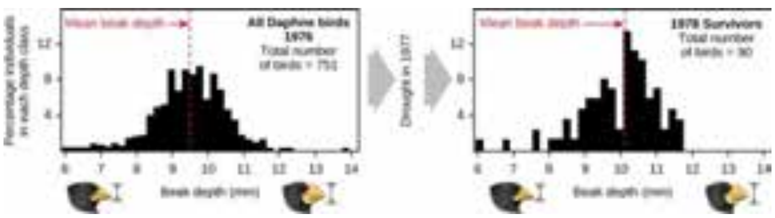


FIGURE 5.4

A drought on the Galápagos island of Daphne Major in 1977 reduced the number of small seeds available to finches, causing many of the small-beaked finches to die. This caused an increase in the finches' average beak size between 1976 and 1978.

Variation and Adaptation

Natural selection can only take place if there is variation, or differences, among individuals in a population. Importantly, these differences must have some genetic basis; otherwise, selection will not lead to change in the next generation. This is critical because variation among individuals can be caused by non-genetic reasons, such as an individual being taller because of better nutrition rather than different genes.

Genetic diversity in a population comes from two main sources: mutation and sexual reproduction. Mutation, a change in DNA, is the ultimate source of new alleles or new genetic variation in any population. An individual that has a mutated gene might have a different trait than other individuals in the population. However, this is not always the case. A mutation can have one of three outcomes on the organisms' appearance (or phenotype):

- A mutation may affect the phenotype of the organism in a way that gives it reduced fitness—lower likelihood of survival, resulting in fewer offspring.
- A mutation may produce a phenotype with a beneficial effect on fitness.
- Many mutations, called neutral mutations, will have no effect on fitness.

Mutations may also have a whole range of effect sizes on the fitness of the organism that expresses them in their phenotype, from a small effect to a great effect. Sexual reproduction and crossing over in meiosis also lead to genetic diversity: when two parents reproduce, unique combinations of alleles assemble to produce unique genotypes and, thus, phenotypes in each of the offspring.

A heritable trait that aids the survival and reproduction of an organism in its present environment is called an adaptation. An adaptation is a "match" of the organism to the environment. Adaptation to an environment comes about when a change in the range of genetic variation occurs over time that increases or maintains the match of the population with its environment. The variations in finch beaks shifted from generation to generation providing adaptation to food availability.

Whether or not a trait is favorable depends on the environment at the time. The same traits do not always have the same relative benefit or disadvantage because environmental conditions can change. For example, finches with large bills were benefited in one climate, while small bills were a disadvantage; in a different climate, the relationship reversed.

### Patterns of Evolution

The evolution of species has resulted in enormous variation in form and function. When two species evolve in different directions from a common point, it is called divergent evolution. Such divergent evolution can be seen in the forms of the reproductive organs of flowering plants, which share the same basic anatomies; however, they can look very different as a result of selection in different physical environments, and adaptation to different kinds of pollinators (Figure 5.5).

FIGURE 5.5
Flowering plants evolved from a common ancestor. Notice that the (a) dense blazing star and (b) purple coneflower vary in appearance, yet both share a similar basic morphology. (credit a, b: modification of work by Cory Zanker)

In other cases, similar phenotypes evolve independently in distantly related species. For example, flight has evolved in both bats and insects, and they both have structures we refer to as wings, which are adaptations to flight. The wings of bats and insects, however, evolved from very different original structures. When similar structures arise through evolution independently in different species it is called convergent evolution. The wings of bats and insects are called analogous structures; they are similar in function and appearance, but do not share an origin in a common ancestor. Instead they evolved independently in the two lineages. The wings of a hummingbird and an ostrich are homologous structures, meaning they share similarities (despite their differences resulting from evolutionary divergence). The wings of hummingbirds and ostriches did not evolve independently in the hummingbird lineage and the ostrich lineage—they descended from a common ancestor with wings.

### The Modern Synthesis

The mechanisms of inheritance, genetics, were not understood at the time Darwin and Wallace were developing their idea of natural selection. This lack of understanding was a stumbling block to comprehending many aspects of evolution. In fact, blending inheritance was the predominant (and incorrect) genetic theory of the time, which made it difficult to understand how natural selection might operate. Darwin and Wallace were unaware of the genetics work by Austrian monk Gregor Mendel, which was published in 1866, not long after publication of *On the Origin of Species*. Mendel's work was rediscovered in the early twentieth century at which time geneticists were rapidly coming to an understanding of the basics of inheritance. Initially, the newly discovered particulate nature of genes made it difficult for biologists to understand how gradual evolution could occur. But over the next few decades genetics and evolution were integrated in what became known as the modern synthesis—the coherent understanding of the relationship between natural selection and genetics that took shape by the 1940s and is generally accepted today. In sum, the modern synthesis describes how evolutionary pressures, such as natural selection, can affect a population's genetic makeup, and, in turn, how this can result in the gradual evolution of populations and species. The theory also connects this gradual change of a population over time, called microevolution, with the processes that gave rise to new species and higher taxonomic groups with widely divergent characters, called macroevolution.

### Population Genetics

Recall that a gene for a particular character may have several variants, or alleles, that code for different traits associated with that character. For example, in the ABO blood type system in humans, three alleles determine the particular blood-type protein on the surface of red blood cells. Each individual in a population of diploid organisms can only carry two alleles for a particular gene, but more than two may be present in the individuals that make up the population. Mendel followed alleles as they were inherited from parent to offspring. In the early twentieth century, biologists began to study what happens to all the alleles in a population in a field of study known as population genetics.

Until now, we have defined evolution as a change in the characteristics of a population of organisms, but behind that phenotypic change is genetic change. In population genetic terms, evolution is defined as a change in the frequency of an allele in a population. Using the ABO system as an example, the frequency of one of the alleles, $I^A$, is the number of copies of that allele divided by all the copies of the ABO gene in the population. For example, a study in Jordan found a frequency of $I^A$ to be 26.1 percent. The $I^B$, $I^0$ alleles made up 13.4 percent and 60.5 percent of the alleles respectively, and all of the frequencies add up to 100 percent. A change in this frequency over time would constitute evolution in the population.

There are several ways the allele frequencies of a population can change. One of those ways is natural selection. If a given allele confers a phenotype that allows an individual to have more offspring that survive and reproduce, that allele, by virtue of being inherited by those offspring, will be in greater frequency in the next generation. Since allele frequencies always add up to 100 percent, an increase in the frequency of one allele always means a corresponding decrease in one or more of the other alleles. Highly beneficial alleles may, over a very few generations, become "fixed" in this way, meaning that every individual of the population will carry the allele. Similarly, detrimental alleles may be swiftly eliminated from the gene pool, the sum of all the alleles in a population. Part of the study of population genetics is tracking how selective forces change the allele frequencies in a population over time, which can give scientists clues regarding the selective forces that may be operating on a given population. The studies of changes in wing coloration in the peppered moth from mottled white to dark in response to soot-covered tree trunks and then back to mottled white when factories stopped producing so much soot is a classic example of studying evolution in natural populations (Figure 5.6).

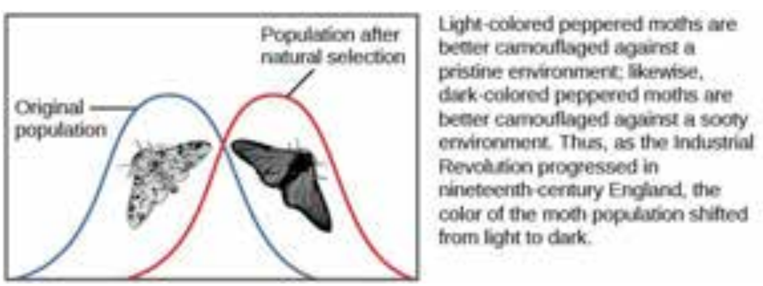


FIGURE 5.6

As the Industrial Revolution caused trees to darken from soot, darker colored peppered moths were better camouflaged than the lighter colored ones, which caused there to be more of the darker colored moths in the population.

In the early twentieth century, English mathematician **Godfrey Hardy** and German physician **Wilhelm Weinberg** independently provided an explanation for a somewhat counterintuitive concept. Hardy's original explanation was in response to a misunderstanding as to why a "dominant" allele, one that masks a recessive allele, should not increase in frequency in a population until it eliminated all the other alleles. The question resulted from a common confusion about what "dominant" means, but it forced Hardy, who was not even a biologist, to point out that if there are no factors that affect an allele frequency those frequencies will remain constant from one generation to the next. This principle is now known as the **Hardy-Weinberg equilibrium**. The theory states that a population's allele and genotype frequencies are inherently stable—unless some kind of evolutionary force is acting on the population, the population would carry the same alleles in the same proportions generation after generation. Individuals would, as a whole, look essentially the same and this would be unrelated to whether the alleles were dominant or recessive. The four most important evolutionary forces, which will disrupt the equilibrium, are **natural selection**, **mutation**, genetic drift, and migration into or out of a population. A fifth factor, **nonrandom mating**, will also disrupt the Hardy-Weinberg equilibrium but only by shifting genotype frequencies, not allele frequencies. In nonrandom mating, individuals are more likely to mate with like individuals (or unlike individuals) rather than at random. Since nonrandom mating does not change allele frequencies, it does not cause evolution directly. Natural selection has been described. Mutation creates one allele out of another one and changes an allele's frequency by a small, but continuous amount each generation. Each allele is generated by a low, constant mutation rate that will slowly increase the allele's frequency in a population if no other forces act on the allele. If natural selection acts against the allele, it will be removed from the population at a low rate leading to a frequency that results from a balance between selection and mutation. This is one reason that genetic diseases remain in the human population at very low frequencies. If the allele is favored by selection, it will increase in frequency. Genetic drift causes random changes in allele frequencies when populations are small. Genetic drift can often be important in evolution, as discussed in the next section. Finally, if two populations of a species have different allele frequencies, migration of individuals between them will cause frequency changes in both populations. As it happens, there is no population in which one or more of these processes are not operating, so populations are always evolving, and the Hardy-Weinberg equilibrium will never be exactly observed. However, the Hardy-Weinberg principle gives scientists a baseline expectation for allele frequencies in a non-evolving population to which they can compare evolving populations and thereby infer what evolutionary forces might be at play. The population is evolving if the frequencies of alleles or genotypes deviate from the value expected from the Hardy-Weinberg principle.

Darwin identified a special case of natural selection that he called sexual selection. Sexual selection affects an individual's ability to mate and thus produce offspring, and it leads to the evolution of dramatic traits that often appear maladaptive in terms of survival but persist because they give their owners greater reproductive success. Sexual selection occurs in two ways: through male–male competition for mates and through female selection of mates. Male–male competition takes the form of conflicts between males, which are often ritualized, but may also pose significant threats to a male's survival. Sometimes the competition is for territory, with females more likely to mate with males with higher quality territories. Female choice occurs when females choose a male based on a particular trait, such as feather colors, the performance of a mating dance, or the building of an elaborate structure. In some cases male–male competition and female choice combine in the mating process. In each of these cases, the traits selected for, such as fighting ability or feather color and length, become enhanced in the males. In general, it is thought that sexual selection can proceed to a point at which natural selection against a character's further enhancement prevents its further evolution because it negatively impacts the male's ability to survive. For example, colorful feathers or an elaborate display make the male more obvious to predators.

# 5.2 Mechanisms of Evolution

The Hardy-Weinberg equilibrium principle says that allele frequencies in a population will remain constant in the absence of the four factors that could change them (OpenStax College, 2013). Those factors are natural selection, mutation, genetic drift, and migration (gene flow). In fact, we know they are probably always affecting populations.

### Natural Selection

We have discussed natural selection in the previous section. Recall that alleles are expressed in a phenotype. Depending on the environmental conditions, the phenotype confers an advantage or disadvantage to the individual with the phenotype relative to the other phenotypes in the population. If it is an advantage, then that individual will likely have more offspring than individuals with the other phenotypes, and this will mean that the allele behind the phenotype will have greater representation in the next generation. If conditions remain the same, those offspring, which are carrying the same allele, will also benefit. Over time, the allele will increase in frequency in the population.

### Mutation

Mutation is a source of new alleles in a population. Mutation is a change in the DNA sequence of the gene. A mutation can change one allele into another, but the net effect is a change in frequency. The change in frequency resulting from mutation is small, so its effect on evolution is small unless it interacts with one of the other factors, such as selection. A mutation may produce an allele that is selected against, selected for, or selectively neutral. Harmful mutations are removed from the population by selection and will generally only be found in very low frequencies equal to the mutation rate. Beneficial mutations will spread through the population through selection, although that initial spread is slow. Whether or not a mutation is beneficial or harmful is determined by whether it helps an organism survive to sexual maturity and reproduce. It should be noted that mutation is the ultimate source of genetic variation in all populations—new alleles, and, therefore, new genetic variations arise through mutation.

### Genetic Drift

Another way a population's allele frequencies can change is genetic drift (5.7), which is simply the effect of chance. Genetic drift is most important in small populations. Drift would be completely absent in a population with infinite individuals, but, of course, no population is this large. Genetic drift occurs because the alleles in an offspring generation are a random sample of the alleles in the parent generation. Alleles may or may not make it into the next generation due to chance events including mortality of an individual, events affecting finding a mate, and even the events affecting which gametes end up in fertilizations. If one individual in a population of ten individuals happens to die before it leaves any offspring to the next generation, all of its genes—a tenth of the population's gene pool—will be suddenly lost. In a population of 100, that 1 individual represents only 1 percent of the overall gene pool; therefore, it has much less impact on the population's genetic structure and is unlikely to remove all copies of even a relatively rare allele.

Imagine a population of ten individuals, half with allele *A* and half with allele *a* (the individuals are haploid). In a stable population, the next generation will also have ten individuals. Choose that generation randomly by flipping a coin ten times and let heads be *A* and tails be *a*. It is unlikely that the next generation will have exactly half of each allele. There might be six of one and four of the other, or some different set of frequencies. Thus, the allele frequencies have changed and evolution has occurred. A coin will no longer work to choose the next generation (because the odds are no longer one half for each allele). The frequency in each generation will drift up and down on what is known as a random walk until at one point either all *A* or all *a* are chosen and that allele is fixed from that point on. This could take a very long time for a large population. This simplification is not very biological, but it can be shown that real populations behave this way. The effect of drift on frequencies is greater the smaller a population is. Its effect is also greater on an allele with a frequency far from one half. Drift will influence every allele, even those that are being naturally selected.

**ART CONNECTION**

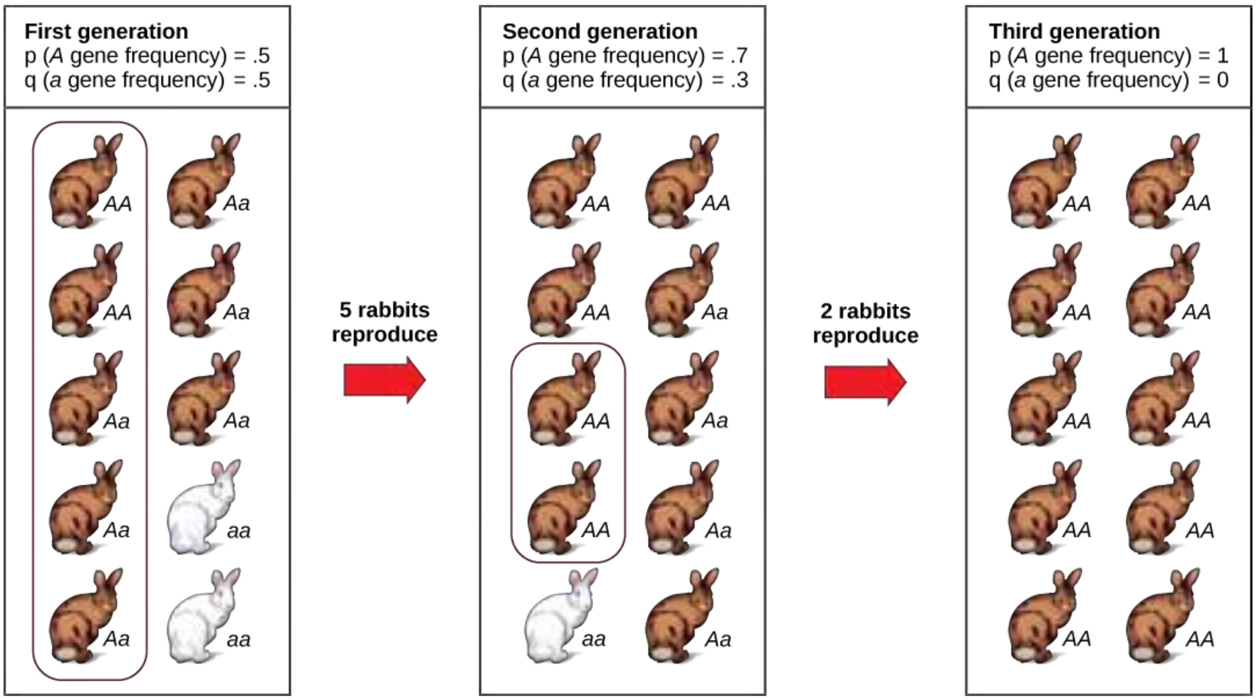


FIGURE 5.7

Genetic drift in a population can lead to the elimination of an allele from a population by chance. In each generation, a random set of individuals reproduces to produce the next generation. The frequency of alleles in the next generation is equal to the frequency of alleles among the individuals reproducing. Do you think genetic drift would happen more quickly on an island or on the mainland?

Genetic drift can also be magnified by natural or human-caused events, such as a disaster that randomly kills a large portion of the population, which is known as the bottleneck effect that results in a large portion of the genome suddenly being wiped out (5.8). In one fell swoop, the genetic structure of the survivors becomes the genetic structure of the entire population, which may be very different from the pre-disaster population. The disaster must be one that kills for reasons unrelated to the organism's traits, such as a hurricane or lava flow. A mass killing caused by unusually cold temperatures at night, is likely to affect individuals differently depending on the alleles they possess that confer cold hardiness.

Another scenario in which populations might experience a strong influence of genetic drift is if some portion of the population leaves to start a new population in a new location, or if a population gets divided by a physical barrier of some kind. In this situation, those individuals are unlikely to be representative of the entire population which results in the founder effect. The founder effect occurs when the genetic structure matches that of the new population's founding fathers and mothers. The founder effect is believed to have been a key factor in the genetic history of the

Afrikaner population of Dutch settlers in South Africa, as evidenced by mutations that are common in Afrikaners


FIGURE 5.8
A chance event or catastrophe can reduce the genetic variability within a population.

but rare in most other populations. This is likely due to a higher-than-normal proportion of the founding colonists, which were a small sample of the original population, carried these mutations. As a result, the population expresses unusually high incidences of Huntington's disease (HD) and Fanconi anemia (FA), a genetic disorder known to cause bone marrow and congenital abnormalities, and even cancer. [1]

**CONCEPT IN ACTION**

Visit this site to learn more about genetic drift and to run simulations of allele changes caused by drift.

### Gene Flow

Another important evolutionary force is gene flow, or the flow of alleles in and out of a population resulting from the migration of individuals or gametes. While some populations are fairly stable, others experience more flux. Many plants, for example, send their seeds far and wide, by wind or in the guts of animals; these seeds may introduce alleles common in the source population to a new population in which they are rare. Gene flow can occur when an individual travels from one geographic location to another and joins a different population of the species. In the example shown here, the brown allele is introduced into the green population.

### Evidence for Evolution

The evidence for evolution is compelling and extensive. Darwin dedicated a large portion of his book, *On the Origin of Species*, identifying patterns in nature that were consistent with evolution and since Darwin our understanding has become clearer and broader. The evidence for evolution is found at all levels of organization in living things and in the extinct species we know about through fossils. **Fossils** provide evidence for the evolutionary change through now extinct forms that led to modern species. For example, there is a rich fossil record that shows the evolutionary transitions from horse ancestors to modern horses (5.9) that document intermediate forms and a gradual adaptation o changing ecosystems. The **anatomy of species** and the **embryological development** of that anatomy reveal common structures in divergent lineages that have been modified over time by evolution. The **geographical distribution** of living species reflects the origins of species in particular geographic locations and the history of continental movements. The **structures of molecules**, like anatomical structures, reflect the relationships of living species and match patterns of similarity expected from descent with modification.

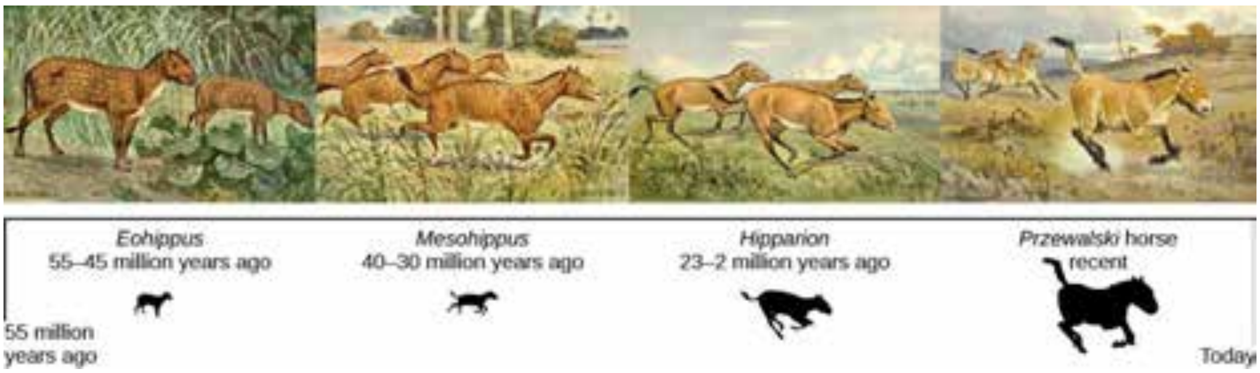


FIGURE 5.9

This illustration shows an artist's renderings of these species derived from fossils of the evolutionary history of the horse and its ancestors. The species depicted are only four from a very diverse lineage that contains many branches, dead ends, and adaptive radiations. One of the trends, depicted here is the evolutionary tracking of a drying climate and increase in prairie versus forest habitat reflected in forms that are more adapted to grazing and predator escape through running. Przewalski's horse is one of a few living species of horse.

## 5.3 Speciation

The biological definition of species, which works for sexually reproducing organisms, is a group of actually or potentially interbreeding individuals (OpenStax College, 2013). According to this definition, one species is distinguished from another by the possibility of matings between individuals from each species to produce fertile offspring. There are exceptions to this rule. Many species are similar enough that hybrid offspring are possible and may often occur in nature, but for the majority of species this rule generally holds. In fact, the presence of hybrids between similar species suggests that they may have descended from a single interbreeding species and that the speciation process may not yet be completed.

Given the extraordinary diversity of life on the planet there must be mechanisms for speciation: the formation of two species from one original species. Darwin envisioned this process as a branching event and diagrammed the process in the only illustration found in *On the Origin of Species* (Figure 5.10). For speciation to occur, two new populations must be formed from one original population, and they must evolve in such a way that it becomes impossible for individuals from the two new populations to interbreed. Biologists have proposed mechanisms by which this could occur that fall into two broad categories. Allopatric speciation, meaning speciation in "other homelands," involves a geographic separation of populations from a parent species and subsequent evolution. Sympatric speciation, meaning speciation in the "same homeland," involves speciation occurring within a parent species while remaining in one location.

Biologists think of speciation events as the splitting of one ancestral species into two descendant species. There is no reason why there might not be more than two species formed at one time except that it is less likely and such multiple events can also be conceptualized as single splits occurring close in time.

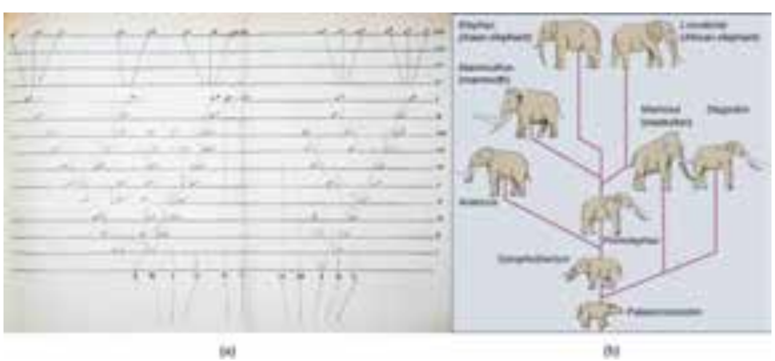

FIGURE 5.10

The only illustration in Darwin's On the Origin of Species is (a) a diagram showing speciation events leading to biological diversity. The diagram shows similarities to phylogenetic charts that are drawn today to illustrate the relationships of species.

(b) Modern elephants evolved from the Palaeomastodon, a species that lived in Egypt 35–50 million years ago.

A geographically continuous population has a gene pool that is relatively homogeneous. Gene flow, the movement of alleles across the range of the species, is relatively free because individuals can move and then mate with individuals in their new location. Thus, the frequency of an allele at one end of a distribution will be similar to the frequency of the allele at the other end. When populations become geographically discontinuous that free-flow of alleles is prevented. When that separation lasts for a period of time, the two populations are able to evolve along different trajectories. Thus, their allele frequencies at numerous genetic loci gradually become more and more different as new alleles independently arise by mutation in each population. Typically, environmental conditions, such as climate, resources, predators, and competitors, for the two populations will differ causing natural selection to favor divergent adaptations in each group. Different histories of genetic drift, enhanced because the populations are smaller than the parent population, will also lead to divergence. Given enough time, the genetic and phenotypic divergence between populations will likely affect characters that influence reproduction enough that were individuals of the two populations brought together, mating would be less likely, or if a mating occurred, offspring would be non-viable or infertile. Many types of diverging characters may affect the reproductive isolation (inability to interbreed) of the two populations. These mechanisms of reproduc- tive isolation can be divided into prezygotic mechanisms (those that operate before fertilization) and postzygotic mechanisms (those that operate after fertilization). Prezygotic mechanisms include traits that allow the individuals to find each other, such as the timing of mating, sensitivity to pheromones, or choice of mating sites. If individuals are able to encounter each other, character divergence may prevent courtship rituals from leading to a mating either because female preferences have changed or male behaviors have changed. Physiological changes may interfere with successful fertilization if mating is able to occur. Postzygotic mechanisms include genetic incompatibilities that prevent proper development of the offspring, or if the offspring live, they may be unable to produce viable gametes themselves as in the example of the mule, the infertile offspring of a female horse and a male donkey.

If the two isolated populations are brought back together and the hybrid offspring that formed from matings between individuals of the two populations have lower survivorship or reduced fertility, then selection will favor individuals that are able to discriminate between potential mates of their own population and the other population. This selection will enhance the reproductive isolation.

Isolation of populations leading to allopatric speciation can occur in a variety of ways: from a river forming a new branch, erosion forming a new valley, or a group of organisms traveling to a new location without the ability to return, such as seeds floating over the ocean to an island. The nature of the geographic separation necessary to isolate populations depends entirely on the biology of the organism and its potential for dispersal. If two flying insect populations took up residence in separate nearby valleys, chances are that individuals from each population would fly back and forth, continuing gene flow. However, if two rodent populations became divided by the formation of a new lake, continued gene flow would be unlikely; therefore, speciation would be more likely.

Biologists group allopatric processes into two categories. If a few members of a species move to a new geographical area, this is called dispersal. If a natural situation arises to physically divide organisms, this is called vicariance. Scientists have documented numerous cases of allopatric speciation taking place. For example, along the west coast of the United States, two separate subspecies of spotted owls exist. The northern spotted owl has genetic and phenotypic differences from its close relative, the Mexican spotted owl, which lives in the south (Figure 5.11). The cause of their initial separation is not clear, but it may have been caused by the glaciers of the ice age dividing an initial population into two.

In some cases, a population of one species disperses throughout an area, and each finds a distinct niche or isolated habitat. Over time, the varied demands of their new lifestyles lead to multiple speciation events originating from a single species, which is called adaptive radiation. From one point of origin, many adaptations evolve causing the species to radiate into several new ones. Island archipelagos like the Hawaiian Islands provide an ideal context for adaptive radiation events because water surrounds each island, which leads to geographical isolation for many organisms (Figure5.12). The Hawaiian honeycreeper illustrates one example of adaptive radiation. From a single species, called the **founder species**, numerous species have evolved, including the eight shown in Figure5.12.

The honeycreeper birds illustrate adaptive radiation. From one original species of bird, multiple others evolved, each with its own distinctive characteristics. Notice the differences in the species' beaks in Figure5.12. Change in the genetic variation for beaks in response to natural selection based on specific food sources in each new habitat led to evolution of a different beak suited to the specific food source. The fruit and seed-eating birds have thicker, stronger beaks which are suited to break hard nuts. The nectar-eating birds have long beaks to dip into flowers to reach their nectar. The insect-eating birds have beaks like swords, appropriate for stabbing and impaling insects. Darwin's finches are another well-studied example of adaptive radiation in an archipelago.


FIGURE 5.11
The northern spotted owl and the Mexican spotted owl inhabit geographically separate locations with different climates and ecosystems. The owl is an example of incipient speciation. (credit "northern spotted owl": modification of work by John and Karen Hollingsworth, USFWS; credit "Mexican spotted owl": modification of work by Bill Radke, USFWS)

### Speciation without Geographic Separation

Can divergence occur if no physical barriers are in place to separate individuals who continue to live and reproduce in the same habitat? A number of mechanisms for sympatric speciation have been proposed and studied.

One form of sympatric speciation can begin with a chromosomal error during meiosis or the formation of a hybrid individual with too many chromosomes. Polyploidy is a condition in which a cell, or organism, has an extra set, or sets, of chromosomes. Scientists have identified two main types of polyploidy that can lead to reproductive isolation of an individual in the polyploid state. In some cases a polyploid individual will have two or more complete sets of chromosomes from its own species in a condition called **autopolyploidy.** The prefix "auto" means self, so the term means multiple chromosomes from one's own species. Polyploidy results from an error in meiosis in which all of the chromosomes move into one cell instead of separating.

For example, if a plant species with $2n = 6$ produces autopolyploid gametes that are also diploid ($2n = 6$, when they should be $n = 3$), the gametes now have twice as many chromosomes as they should have. These new gametes will be incompatible with the normal gametes produced by this plant species. But they could either self-pollinate or reproduce with other autopolyploid plants with gametes having the same diploid number. In this way, sympatric speciation can occur quickly by forming offspring with $4n$ called a tetraploid. These individuals would immediately be able to reproduce only with those of this new kind and not those of the ancestral species. The other form of polyploidy occurs when individuals of two different species reproduce to form a viable offspring called an allopolyploid. The prefix "allo" means "other" (recall from allopatric); therefore, an allopolyploid occurs when gametes from two different species combine.

The cultivated forms of wheat, cotton, and tobacco plants are all allopolyploids. Although polyploidy occurs

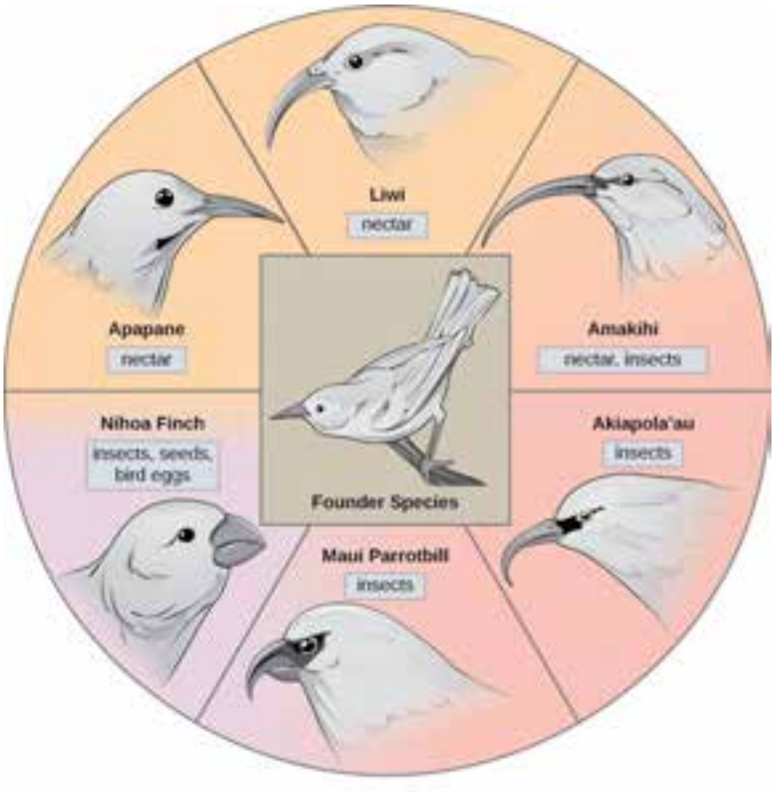


FIGURE 5.12

The honeycreeper birds illustrate adaptive radiation. From one original species of bird, multiple others evolved, each with its own distinctive characteristics.

occasionally in animals, most chromosomal abnormalities in animals are lethal; it takes place most commonly in plants. Scientists have discovered more than 1/2 of all plant species studied relate back to a species evolved through polyploidy.

Sympatric speciation may also take place in ways other than polyploidy. For example, imagine a species of fish that lived in a lake. As the population grew, competition for food also grew. Under pressure to find food, suppose that a group of these fish had the genetic flexibility to discover and feed off another resource that was unused by the other fish. What if this new food source was found at a different depth of the lake? Over time, those feeding on the second food source would interact more with each other than the other fish; therefore they would breed together as well. Offspring of these fish would likely behave as their parents and feed and live in the same area, keeping them separate from the original population. If this group of fish continued to remain separate from the first population, eventually sympatric speciation might occur as more genetic differences accumulated between them.

This scenario does play out in nature, as do others that lead to reproductive isolation. One such place is Lake Victoria in Africa, famous for its sympatric speciation of cichlid fish. Researchers have found hundreds of sympatric speciation events in these fish, which have not only happened in great number, but also over a short period of time. Figure5.13shows this type of speciation among a cichlid fish population in Nicaragua. In this locale, two types of cichlids live in the same geographic location; however, they have come to have different morphologies that allow them to eat various food sources.

Finally, a well-documented example of ongoing sympatric speciation occurred in the apple maggot fly, *Rhagoletis pomonella*, which arose as an isolated population sometime after the introduction of the apple into North America. The native population of flies fed on hawthorn species and is host-specific: it only infests hawthorn trees. Importantly, it also uses the trees as a location to meet for mating. It is hypothesized that either through mutation or a behavioral mistake, flies jumped hosts and met and mated in apple trees, subsequently laying their eggs in apple fruit. The offspring matured and kept their preference for the apple trees effectively dividing the original population into two new populations separated by host species, not by geography. The host jump took place in the nineteenth

FIGURE 5.13

Cichlid fish from Lake Apoyeque, Nicaragua, show evidence of sympatric speciation. Lake Apoyeque, a crater lake, is 1800 years old, but genetic evidence indicates that the lake was populated only 100 years ago by a single population of cichlid fish. Nevertheless, two populations with distinct morphologies and diets now exist in the lake, and scientists believe these populations may be in an early stage of speciation.

century, but there are now measureable differences between the two populations of fly. It seems likely that host specificity of parasites in general is a common cause of sympatric speciation.

# 5.4 Common Misconceptions About Evolution

Although the theory of evolution initially generated some controversy, by 20 years after the publication of *On the Origin of Species* it was almost universally accepted by biologists, particularly younger biologists (OpenStax College, 2013). Nevertheless, the theory of evolution is a difficult concept and misconceptions about how it works abound. In addition, there are those that reject it as an explanation for the diversity of life.

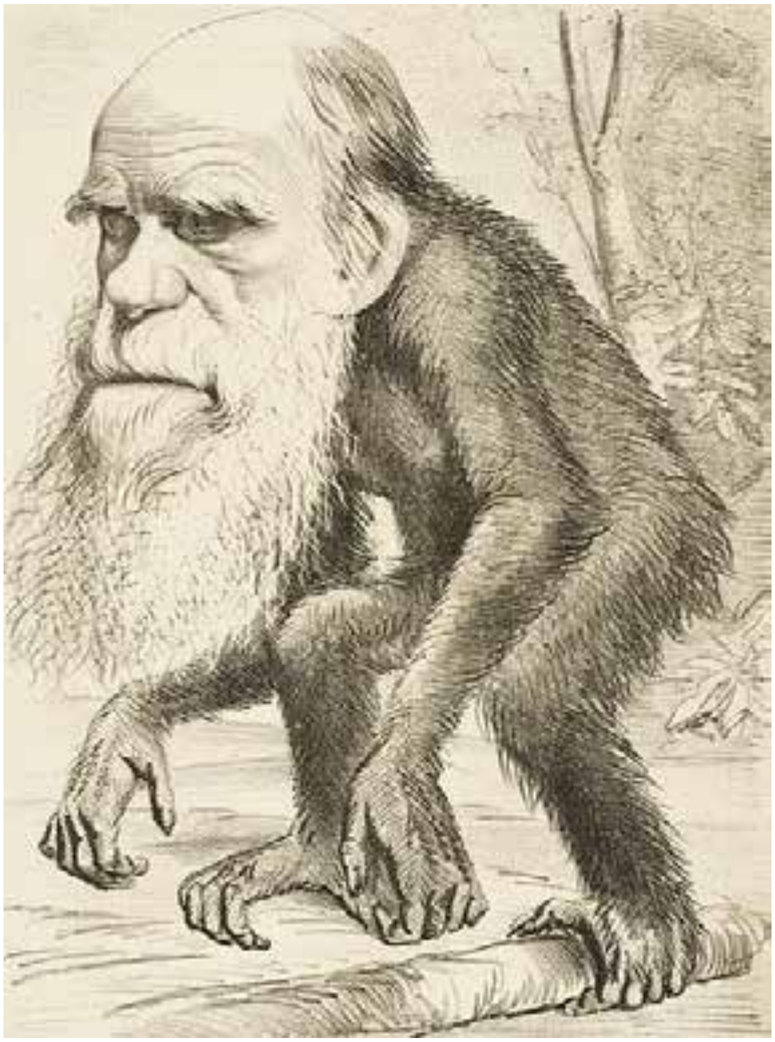

FIGURE 5.14

A Venerable Orang-outang", a caricature of Charles Darwin as an ape published in The Hornet, a satirical magazine in 1871.

Unknown Author. (1871). A venerable orang-outang. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/File:Editorial_cartoon_depicting_Charles_Darwin_as_an_ape_(1871). jpg.

**"Evolution Is Just a Theory"**

Critics of the theory of evolution dismiss its importance by purposefully confounding the everyday usage of the word "theory" with the way scientists use the word. In science, a "theory" is understood to be a concept that has been extensively tested and supported over time. We have a theory of the atom, a theory of gravity, and the theory of relativity, each of which describes what scientists understand to be facts about the world. In the same way, the theory of evolution describes facts about the living world. As such, a theory in science has survived significant efforts to discredit it by scientists, who are naturally skeptical. While theories can sometimes be overturned or revised, this does not lessen their weight but simply reflects the constantly evolving state of scientific knowledge. In contrast, a "theory" in common vernacular means a guess or suggested explanation for something. This meaning is more akin to the concept of a "hypothesis" used by scientists, which is a tentative explanation for something that is proposed to either be supported or disproved. When critics of evolution say evolution is "just a theory," they are implying that there is little evidence supporting it and that it is still in the process of being rigorously tested. This is a mischaracterization. If this were the case, geneticist Theodosius Dobzhansky would not have said that "nothing in biology makes sense, except in the light of evolution."

**"Individuals Evolve"**

An individual is born with the genes it has—these do not change as the individual ages. Therefore, an individual cannot evolve or adapt through natural selection. Evolution is the change in genetic composition of a population over time, specifically over generations, resulting from differential reproduction of individuals with certain alleles. Individuals do change over their lifetime, but this is called development; it involves changes programmed by the set of genes the individual acquired at birth in coordination with the individual's environment. When thinking about the evolution of a characteristic, it is probably best to think about the change of the average value of the characteristic in the population over time. For example, when natural selection leads to bill-size change in medium ground finches in the Galápagos, this does not mean that individual bills on the finches are changing. If one measures the average bill size among all individuals in the population at one time, and then measures the average bill size in the population several years later after there has been a strong selective pressure, this average value may be different as a result of evolution. Although some individuals may survive from the first time to the second, those individuals will still have the same bill size. However, there may be enough new individuals with different bill sizes to change the average bill size.

**"Evolution Explains the Origin of Life"**

It is a common misunderstanding that evolution includes an explanation of life's origins. Conversely, some of the theory's critics complain that it cannot explain the origin of life. The theory does not try to explain the origin of life. The theory of evolution explains how populations change over time and how life diversifies—the origin of species. It does not shed light on the beginnings of life including the origins of the first cells, which is how life is defined. The mechanisms of the origin of life on Earth are a particularly difficult problem because it occurred a very long time ago, over a very long time, and presumably just occurred once. Importantly, biologists believe that the presence of life on Earth precludes the possibility that the events that led to life on Earth can be repeated because the intermediate stages would immediately become food for existing living things. The early stages of life included the formation of organic molecules such as carbohydrates, amino acids, or nucleotides. If these were formed from inorganic precursors today, they would simply be broken down by living things. The early stages of life also probably included more complex aggregations of molecules into enclosed structures with an internal environment, a boundary layer of some form, and the external environment. Such structures, if they were formed now, would be quickly consumed or broken down by living organisms. However, once a mechanism of inheritance was in place in the form of a molecule like DNA or RNA, either within a cell or within a pre-cell, these entities would be subject to the principle of natural selection. More effective reproducers would increase in frequency at the expense of inefficient reproducers. So while evolution does not explain the origin of life, it may have something to say about some of the processes operating once pre-living entities acquired certain properties.

**"Organisms Evolve on Purpose"**

Statements such as "organisms evolve in response to a change in an environment," are quite common. There are two easy misunderstandings possible with such a statement. First of all, the statement must not be understood to mean that individual organisms evolve, as was discussed above. The statement is shorthand for "a population evolves in response to a changing environment." However, a second misunderstanding may arise by interpreting the statement to mean that the evolution is somehow intentional. A changed environment results in some individuals in the population, those with particular phenotypes, benefiting and, therefore, producing proportionately more offspring than other phenotypes. This results in change in the population if the characters are genetically determined. It is also important to understand that the variation that natural selection works on is already in a population and does not arise in response to an environmental change. For example, applying antibiotics to a population of bacteria will, over time, select for a population of bacteria that are resistant to antibiotics. The resistance, which is caused by a gene, did not arise by mutation because of the application of the antibiotic. The gene for resistance was already present in the gene pool of the bacteria, likely at a low frequency. The antibiotic, which kills the bacterial cells without the resistance gene, strongly selects for individuals that are resistant, since these would be the only ones that survived and divided. Experiments have demonstrated that mutations for antibiotic resistance do not arise as a result of antibiotic application. In a larger sense, evolution is also not goal directed. Species do not become "better" over time; they simply track their changing environment with adaptations that maximize their reproduction in a particular environment at a particular time. Evolution has no goal of making faster, bigger, more complex, or even smarter species. This kind of language is common in popular literature. Certain organisms, ourselves included, are described as the "pinnacle" of evolution, or "perfected" by evolution. What characteristics evolve in a species are a function of the variation present and the environment, both of which are constantly changing in a non-directional way. What trait is fit in one environment at one time may well be fatal at some point in the future. This holds equally well for a species of insect as it does the human species.

### "Evolution Is Controversial among Scientists"

The theory of evolution was controversial when it was first proposed in 1859, yet within 20 years virtually every working biologist had accepted evolution as the explanation for the diversity of life. The rate of acceptance was extraordinarily rapid, partly because Darwin had amassed an impressive body of evidence. The early controversies involved both scientific arguments against the theory and the arguments of religious leaders. It was the arguments of the biologists that were resolved after a short time, while the arguments of religious leaders have persisted to this day. The theory of evolution replaced the predominant theory at the time that species had all been specially created within relatively recent history. Despite the prevalence of this theory, it was becoming increasingly clear to naturalists during the nineteenth century that it could no longer explain many observations of geology and the living world. The persuasiveness of the theory of evolution to these naturalists lay in its ability to explain these phenomena, and it continues to hold extraordinary explanatory power to this day. Its continued rejection by some religious leaders results from its replacement of special creation, a tenet of their religious belief. These leaders cannot accept the replacement of special creation by a mechanistic process that excludes the actions of a deity as an explanation for the diversity of life including the origins of the human species. It should be noted, however, that most of the major denominations in the United States have statements supporting the acceptance of evidence for evolution as compatible with their theologies. The nature of the arguments against evolution by religious leaders has evolved over time. One current argument is that the theory is still controversial among biologists. This claim is simply not true. The number of working scientists who reject the theory of evolution, or question its validity and say so, is small. A Pew Research poll in 2009 found that 97 percent of the 2500 scientists polled believe species evolve. The support for the theory is reflected in signed statements from many scientific societies such as the American Association for the Advancement of Science, which includes working scientists as members. Many of the scientists that reject or question the theory of evolution are non-biologists, such as engineers, physicians, and chemists. There are no experimental results or research programs that contradict the theory. There are no papers published in peer-reviewed scientific journals that appear to refute the theory. The latter observation might be considered a consequence of suppression of dissent, but it must be remembered that scientists are skeptics and that there is a long history of published reports that challenged scientific orthodoxy in unpopular ways. Examples include the endosymbiotic theory of eukaryotic origins, the theory of group selection, the microbial cause of stomach ulcers, the asteroid- impact theory of the Cretaceous extinction, and the theory of plate tectonics. Research with evidence and ideas with scientific merit are considered by the scientific community. Research that does not meet these standards is rejected.

### "Other Theories Should Be Taught"

A common argument from some religious leaders is that alternative theories to evolution should be taught in public schools. Critics of evolution use this strategy to create uncertainty about the validity of the theory without offering actual evidence. In fact, there are no viable alternative scientific theories to evolution. The last such theory, proposed by Lamarck in the nineteenth century, was replaced by the theory of natural selection. A single exception was a research program in the Soviet Union based on Lamarck's theory during the early twentieth century that set that country's agricultural research back decades. Special creation is not a viable alternative scientific theory because it is not a scientific theory, since it relies on an untestable explanation. Intelligent design, despite the claims of its proponents, is also not a scientific explanation. This is because intelligent design posits the existence of an unknown designer of living organisms and their systems. Whether the designer is unknown or supernatural, it is a cause that cannot be measured; therefore, it is not a scientific explanation. There are two reasons not to teach nonscientific theories. First, these explanations for the diversity of life lack scientific usefulness because they do not, and cannot, give rise to research programs that promote our understanding of the natural world. Experiments cannot test non-material explanations for natural phenomena. For this reason, teaching these explanations as science in public schools is not in the public interest. Second, in the United States, it is illegal to teach them as science because the U.S. Supreme Court and lower courts have ruled that the teaching of religious belief, such as special creation or intelligent design, violates the establishment clause of the First Amendment of the U.S. Constitution, which prohibits government sponsorship of a particular religion.

# 5.5 Resources

## Summary

Evolution by natural selection arises from three conditions: individuals within a species vary, some of those variations are heritable, and organisms have more offspring than resources can support. The consequence is that individuals with relatively advantageous variations will be more likely to survive and have higher reproductive rates than those individuals with different traits. The modern synthesis of evolutionary theory grew out of the reconciliation of Darwin's, Wallace's, and Mendel's thoughts on evolution and heredity. Population genetics is a theoretical framework for describing evolutionary change in populations through the change in allele frequencies. Population genetics defines evolution as a change in allele frequency over generations. In the absence of evolutionary forces allele frequencies will not change in a population; this is known as Hardy-Weinberg equilibrium principle. The evidence for evolution is found at all levels of organization in living things and in the extinct species we know about through fossils. Fossils provide evidence for the evolutionary change through now extinct forms that led to modern species. Speciation occurs along two main pathways: geographic separation (allopatric speciation) and through mechanisms that occur within a shared habitat (sympatric speciation). Both pathways force reproductive isolation between populations.

## Review Questions

1. If a person scatters a handful of plant seeds from one species in an area, how would natural selection work in this situation?
2. Explain the Hardy-Weinberg principle of equilibrium.
3. Describe natural selection and give an example of natural selection at work in a population.
4. Two species of fish had recently undergone sympatric speciation. The males of each species had a different coloring through which females could identify and choose a partner from her own species. After some time, pollution made the lake so cloudy it was hard for females to distinguish colors. What might take place in this situation?
5. How does the scientific meaning of "theory" differ from the common, everyday meaning of the word?
6. Explain the following terms: adaptation, bottleneck effect, modern synthesis.

# 5.6 References

OpenStax College. (2013). *Concepts of biology*. Retrieved from http://cnx.org/contents/b3c1e1d2-839c-42b0-a314- e119a8aafbdd@8.10. OpenStax CNX. Available under Creative Commons Attribution License License 3.0 (CC BY 3.0). Modified from Original.

## Supplementary Images

Unknown Author. (1871). A venerable orang-outang. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/File:Editorial_cartoon_depicting_Charles_Darwin_as_an_ape_(1871). jpg.

# CHAPTER 6 Ecosystems and the Biosphere

## Chapter Outline




FIGURE 6.1

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

## Learning Outcomes

After studying this chapter, you should be able to:

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

# 6.1 Energy Flow through Ecosystems

An ecosystem is a community of living organisms and their abiotic (non-living) environment (OpenStax College, 2013). Ecosystems can be small, such as the tide pools found near the rocky shores of many oceans, or large, such as those found in the tropical rainforest of the Amazon in Brazil (Figure6.2).


FIGURE 6.2
A (a) tidal pool ecosystem in Matinicus Island, Maine, is a small ecosystem, while the (b) Amazon rainforest in Brazil is a large ecosystem. (credit a: modification of work by Jim Kuhn; credit b: modification of work by Ivan Mlinaric)

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

### Ecology of Ecosystems

Life in an ecosystem often involves competition for limited resources, which occurs both within a single species and between different species. Organisms compete for food, water, sunlight, space, and mineral nutrients. These resources provide the energy for metabolic processes and the matter to make up organisms' physical structures. Other critical factors influencing community dynamics are the components of its physical environment: a habitat's climate (seasons, sunlight, and rainfall), elevation, and geology. These can all be important environmental variables that determine which organisms can exist within a particular area.

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

Marine ecosystems are the most common, comprising 75 percent of Earth's surface and consisting of three basic types: shallow ocean, deep ocean water, and deep ocean bottom. Shallow ocean ecosystems include extremely biodiverse coral reef ecosystems, yet the deep ocean water is known for large numbers of plankton and krill (small crustaceans) that support it. These two environments are especially important to aerobic respirators worldwide, as the phytoplankton perform 40 percent of all photosynthesis on Earth. Although not as diverse as the other two, deep ocean bottom ecosystems contain a wide variety of marine organisms. Such ecosystems exist even at depths where light is unable to penetrate through the water.

Terrestrial ecosystems, also known for their diversity, are grouped into large categories called biomes. A biome is a large-scale community of organisms, primarily defined on land by the dominant plant types that exist in geographic regions of the planet with similar climatic conditions. Examples of biomes include tropical rainforests, savannas, deserts, grasslands, temperate forests, and tundras. Grouping these ecosystems into just a few biome categories obscures the great diversity of the individual ecosystems within them. For example, the saguaro cacti (*Carnegiea gigantean*) and other plant life in the Sonoran Desert, in the United States, are relatively diverse compared with the desolate rocky desert of Boa Vista, an island off the coast of Western Africa (Figure 6.3).

FIGURE 6.3

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

### Ecosystems and Disturbance

Ecosystems are complex with many interacting parts. They are routinely exposed to various disturbances: changes in the environment that affect their compositions, such as yearly variations in rainfall and temperature. Many disturbances are a result of natural processes. For example, when lightning causes a forest fire and destroys part of a forest ecosystem, the ground is eventually populated with grasses, followed by bushes and shrubs, and later mature trees: thus, the forest is restored to its former state. This process is so universal that ecologists have given it a name—succession. The impact of environmental disturbances caused by human activities is now as significant as the changes wrought by natural processes. Human agricultural practices, air pollution, acid rain, global deforestation, overfishing, oil spills, and illegal dumping on land and into the ocean all have impacts on ecosystems.

Equilibrium is a dynamic state of an ecosystem in which, despite changes in species numbers and occurrence, biodiversity remains somewhat constant. In ecology, two parameters are used to measure changes in ecosystems: resistance and resilience. The ability of an ecosystem to remain at equilibrium in spite of disturbances is called resistance. The speed at which an ecosystem recovers equilibrium after being disturbed is called resilience. Ecosystem resistance and resilience are especially important when considering human impact. The nature of an ecosystem may change to such a degree that it can lose its resilience entirely. This process can lead to the complete destruction or irreversible altering of the ecosystem.

### Food Chains and Food Webs

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

In many ecosystems, the base, or foundation, of the food chain consists of photosynthetic organisms (plants or phytoplankton), which are called producers. The organisms that consume the producers are herbivores: the primary consumers. Secondary consumers are usually carnivores that eat the primary consumers. Tertiary consumers are carnivores that eat other carnivores. Higher-level consumers feed on the next lower trophic levels, and so on, up to the organisms at the top of the food chain: the apex consumers. In the Lake Ontario food chain, shown in Figure 6.4, the Chinook salmon is the apex consumer at the top of this food chain.

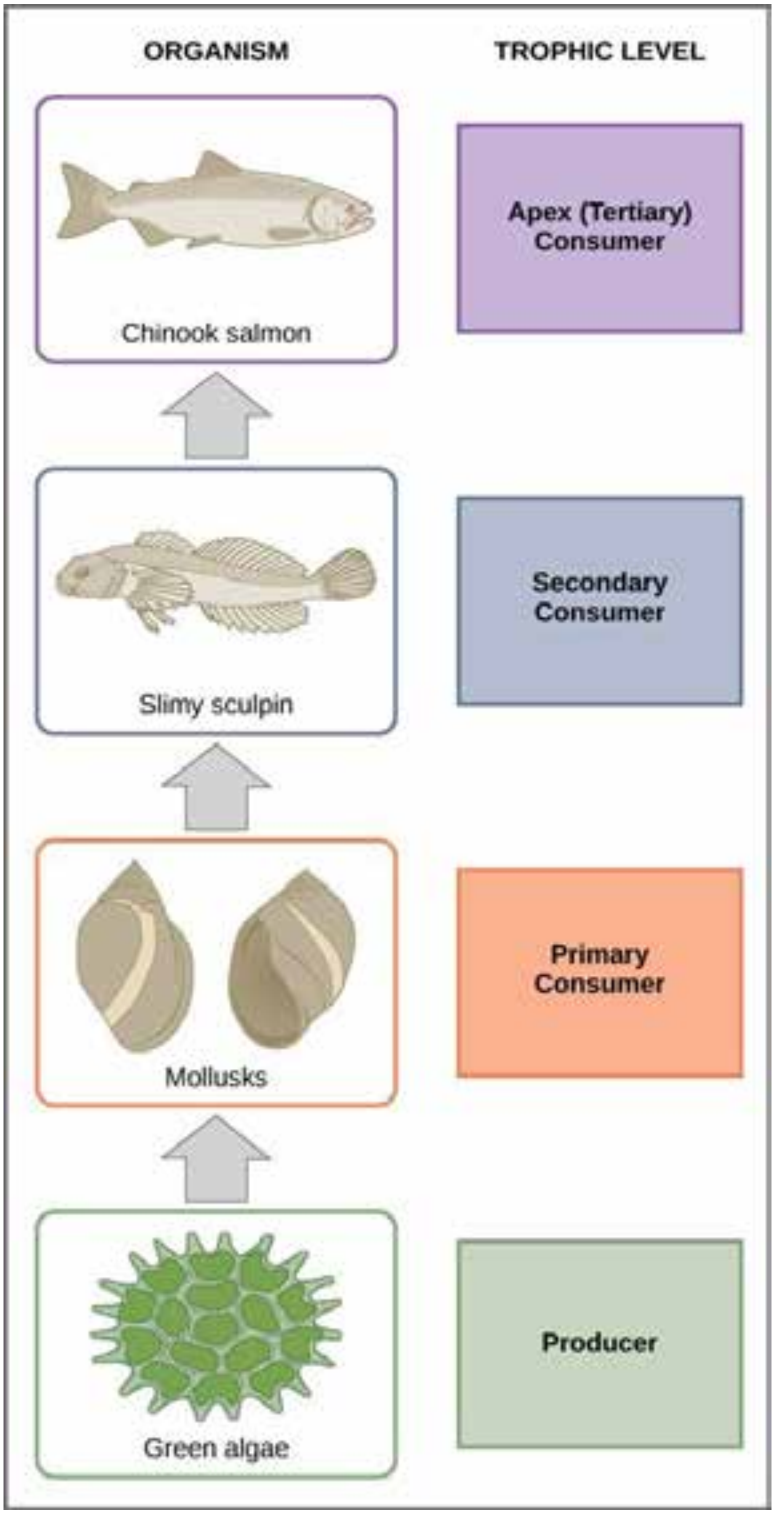


FIGURE 6.4
These are the trophic levels of a food chain in Lake Ontario at the United States–Canada border. Energy and nutrients flow from photosynthetic green algae at the base to the top of the food chain: the Chinook salmon. (credit: modification of work by National Oceanic and Atmospheric Administration/NOAA)

One major factor that limits the number of steps in a food chain is energy. Energy is lost at each trophic level and between trophic levels as heat and in the transfer to decomposers (Figure 6.5). Thus, after a limited number of trophic energy transfers, the amount of energy remaining in the food chain may not be great enough to support viable populations at yet a higher trophic level.

There is a one problem when using food chains to describe most ecosystems. Even when all organisms are grouped

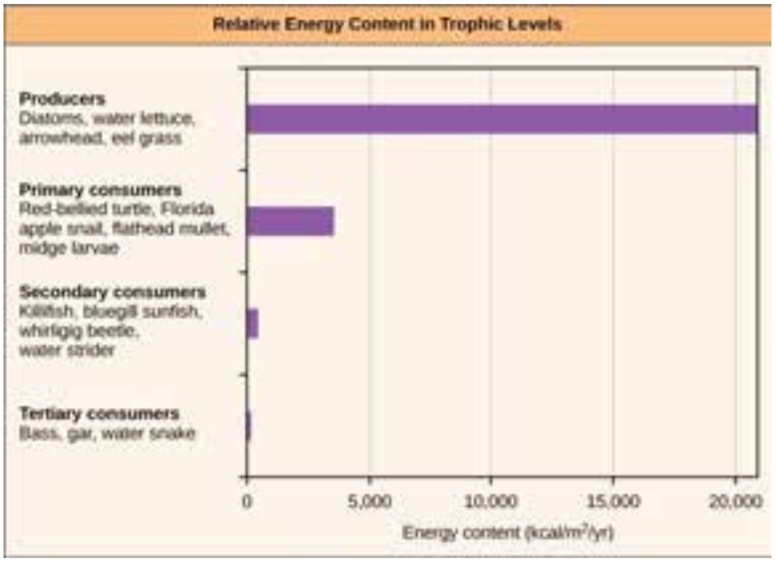


FIGURE 6.5

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

into appropriate trophic levels, some of these organisms can feed on more than one trophic level; likewise, some of these organisms can also be fed on from multiple trophic levels. In addition, species feed on and are eaten by more than one species. In other words, the linear model of ecosystems, the food chain, is a hypothetical, overly simplistic representation of ecosystem structure. A holistic model—which includes all the interactions between different species and their complex interconnected relationships with each other and with the environment—is a more accurate and descriptive model for ecosystems. A food web is a concept that accounts for the multiple trophic (feeding) interactions between each species and the many species it may feed on, or that feed on it. In a food web, the several trophic connections between each species and the other species that interact with it may cross multiple trophic levels. The matter and energy movements of virtually all ecosystems are more accurately described by food webs (Figure 6.6).

Two general types of food webs are often shown interacting within a single ecosystem. A grazing food web has plants or other photosynthetic organisms at its base, followed by herbivores and various carnivores. A detrital food web consists of a base of organisms that feed on decaying organic matter (dead organisms), including decomposers (which break down dead and decaying organisms) and detritivores (which consume organic detritus). These organisms are usually bacteria, fungi, and invertebrate animals that recycle organic material back into the biotic part of the ecosystem as they themselves are consumed by other organisms. As ecosystems require a method to recycle material from dead organisms, grazing food webs have an associated detrital food web. For example, in a meadow ecosystem, plants may support a grazing food web of different organisms, primary and other levels of consumers, while at the same time supporting a detrital food web of bacteria and fungi feeding off dead plants and animals. Simultaneously, a detrital food web can contribute energy to a grazing food web, as when a robin eats an earthworm.

### How Organisms Acquire Energy in a Food Web

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

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

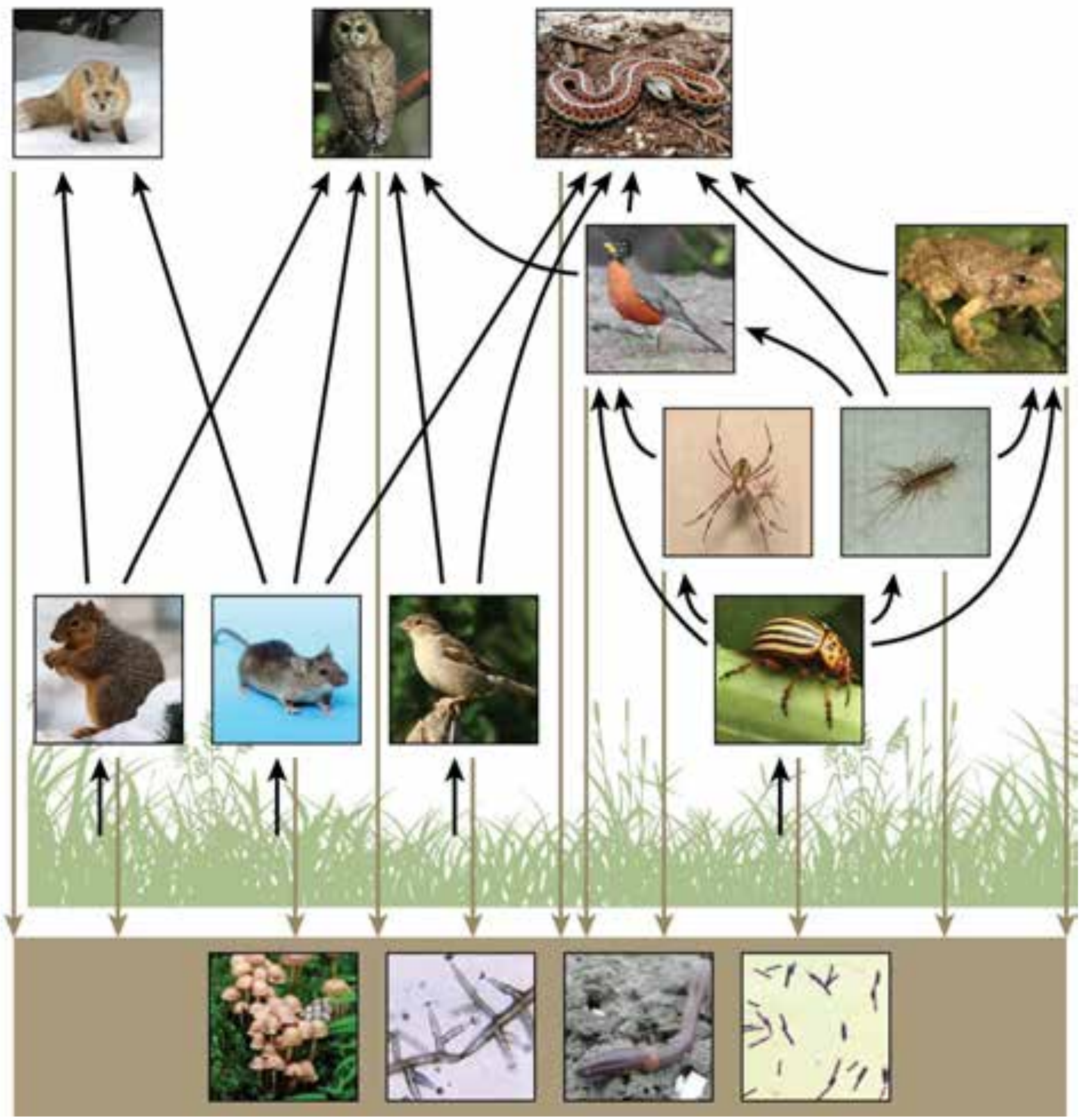

FIGURE 6.6

This food web shows the interactions between organisms across trophic levels. Arrows point from an organism that is consumed to the organism that consumes it. All the producers and consumers eventually become nourishment for the decomposers (fungi, mold, earthworms, and bacteria in the soil). (credit "fox": modification of work by Kevin Bacher, NPS; credit "owl": modification of work by John and Karen Hollingsworth, USFWS; credit "snake": modification of work by Steve Jurvetson; credit "robin": modification of work by Alan Vernon; credit "frog": modification of work by Alessandro Catenazzi; credit "spider": modification of work by "Sanba38"/Wikimedia Commons; credit "centipede": modification of work by "Bauerph"/Wikimedia Commons; credit "squirrel": modification of work by Dawn Huczek; credit "mouse": modification of work by NIGMS, NIH; credit "sparrow": modification of work by David Friel; credit "beetle": modification of work by Scott Bauer, USDA Agricultural Research Service; credit "mushrooms": modification of work by Chris Wee; credit "mold": modification of work by Dr. Lucille Georg, CDC; credit "earthworm": modification of work by Rob Hille; credit "bacteria": modification of work by Don Stalons, CDC) acquire energy through the consumption and digestion of other living or previously living organisms.

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

Photoautotrophs, such as plants, algae, and photosynthetic bacteria, are the energy source for a majority of the world's ecosystems. These ecosystems are often described by grazing and detrital food webs. Photoautotrophs harness the Sun's solar energy by converting it to chemical energy in the form of ATP (and NADP). The energy stored in ATP is used to synthesize complex organic molecules, such as glucose. The rate at which photosynthetic producers incorporate energy from the Sun is called gross primary productivity. However, not all of the energy incorporated by producers is available to the other organisms in the food web because producers must also grow and reproduce, which consumes energy. Net primary productivity is the energy that remains in the producers after accounting for these organisms' respiration and heat loss. The net productivity is then available to the primary consumers at the next trophic level.

Chemoautotrophs are primarily bacteria and archaea that are found in rare ecosystems where sunlight is not available, such as those associated with dark caves or hydrothermal vents at the bottom of the ocean (Figure6.7). Many chemoautotrophs in hydrothermal vents use hydrogen sulfide ($H_2S$), which is released from the vents as a source of chemical energy; this allows them to synthesize complex organic molecules, such as glucose, for their own energy and, in turn, supplies energy to the rest of the ecosystem.

FIGURE 6.7

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

#### Consequences of Food Webs: Biological Magnification

One of the most important consequences of ecosystem dynamics in terms of human impact is biomagnification (OpenStax College, 2013). Bio- magnification is the increasing concentration of persistent, toxic substances in organisms at each successive trophic level. These are substances that are fat soluble, not water soluble, and are stored in the fat reserves of each organism. Many substances have been shown to biomagnify, including classical studies with the pesticide dichlorodiphenyl- trichloroethane (DDT), which were described in the 1960s bestseller, *Silent Spring* by Rachel Carson. DDT was a commonly used pesticide before its dangers to apex consumers, such as the bald eagle, became known. In aquatic ecosystems, organisms from each trophic level consumed many organisms in the lower level, which caused DDT to increase in birds (apex consumers) that ate fish. Thus, the birds accumulated sufficient amounts of DDT to cause fragility in their eggshells. This effect increased egg breakage during nesting and was shown to have devastating effects on these bird populations. The use of DDT was banned in the United States in the 1970s.

Other substances that biomagnify are polychlorinated biphenyls (PCB), which were used as coolant liquids in the United States until their use was banned in 1979, and heavy metals, such as mercury, lead, and cadmium. These substances are best studied in aquatic ecosystems, where predatory fish species accumulate very high concentrations of toxic substances that are at quite low concentrations in the environment and in producers. As illustrated in a study performed by the NOAA in the Saginaw Bay of Lake Huron of the North American Great Lakes (Figure 6.8), PCB concentrations increased from the producers of the ecosystem (phytoplankton) through the different trophic levels of fish species. The apex consumer, the walleye, has more than four times the amount of PCBs compared to phytoplankton. Also, based on results from other studies, birds that eat these fish may have PCB levels at least one order of magnitude higher than those found in the lake fish.

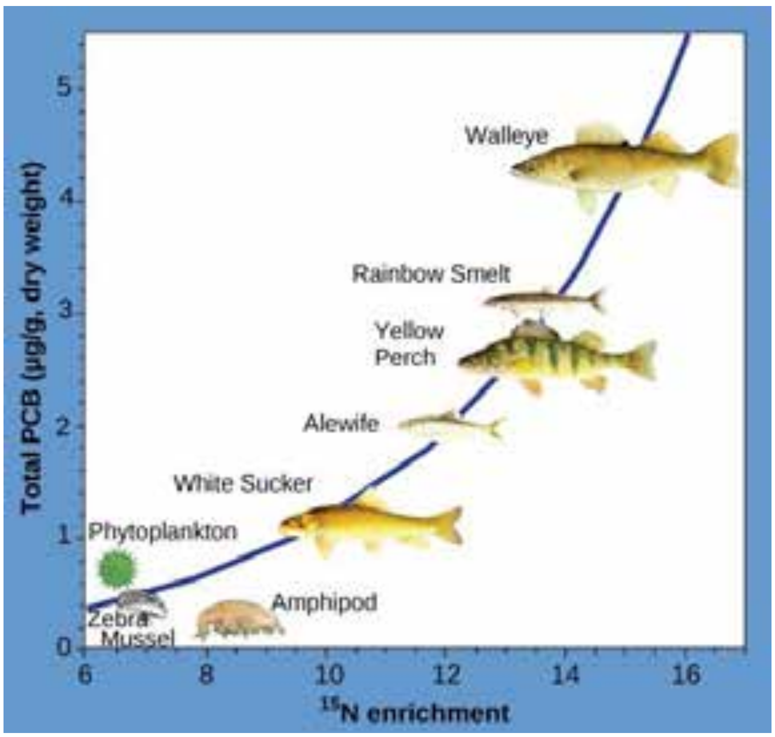


FIGURE 6.8

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

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

## 6.2 Biogeochemical Cycles

Energy flows directionally through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during the transfers between trophic levels (OpenStax College, 2013). Rather than flowing through an ecosystem, the matter that makes up living organisms is conserved and recycled. The six most common elements associated with organic molecules—carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur—take a variety of chemical forms and may exist for long periods in the atmosphere, on land, in water, or beneath Earth's surface. Geologic processes, such as weathering, erosion, water drainage, and the subduction of the continental plates, all play a role in the cycling of elements on Earth. Because geology and chemistry have major roles in the study of this process, the recycling of inorganic matter between living organisms and their nonliving environment is called a biogeochemical cycle.

Water, which contains hydrogen and oxygen, is essential to all living processes. The hydrosphere is the area of Earth where water movement and storage occurs: as liquid water on the surface (rivers, lakes, oceans) and beneath the surface (groundwater) or ice, (polar ice caps and glaciers), and as water vapor in the atmosphere. Carbon is found in all organic macromolecules and is an important constituent of fossil fuels. Nitrogen is a major component of our nucleic acids and proteins and is critical to human agriculture. Phosphorus, a major component of nucleic acids, is one of the main ingredients (along with nitrogen) in artificial fertilizers used in agriculture, which has environmental impacts on our surface water. Sulfur, critical to the three-dimensional folding of proteins (as in disulfide binding), is released into the atmosphere by the burning of fossil fuels.

The cycling of these elements is interconnected. For example, the movement of water is critical for the leaching of nitrogen and phosphate into rivers, lakes, and oceans. The ocean is also a major reservoir for carbon. Thus, mineral nutrients are cycled, either rapidly or slowly, through the entire biosphere between the biotic and abiotic world and from one living organism to another.

### The Water Cycle

Water is essential for all living processes. The human body is more than one-half water and human cells are more than 70 percent water. Thus, most land animals need a supply of fresh water to survive. Of the stores of water on Earth, 97.5 percent is salt water (see Figure 6.9). Of the remaining water, 99 percent is locked as underground water or ice. Thus, less than one percent of fresh water is present in lakes and rivers. Many living things are dependent on this small amount of surface fresh water supply, a lack of which can have important effects on ecosystem dynamics. Humans, of course, have developed technologies to increase water availability, such as digging wells to harvest groundwater, storing rainwater, and using desalination to obtain drinkable water from the ocean. Although this pursuit of drinkable water has been ongoing throughout human history, the supply of fresh water continues to be a major issue in modern times.

The various processes that occur during the cycling of water are illustrated in Figure 6.10. The processes include the following:

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

The water cycle is driven by the Sun's energy as it warms the oceans and other surface waters. This leads to evaporation (water to water vapor) of liquid surface water and sublimation (ice to water vapor) of frozen water, thus moving large amounts of water into the atmosphere as water vapor. Over time, this water vapor condenses into

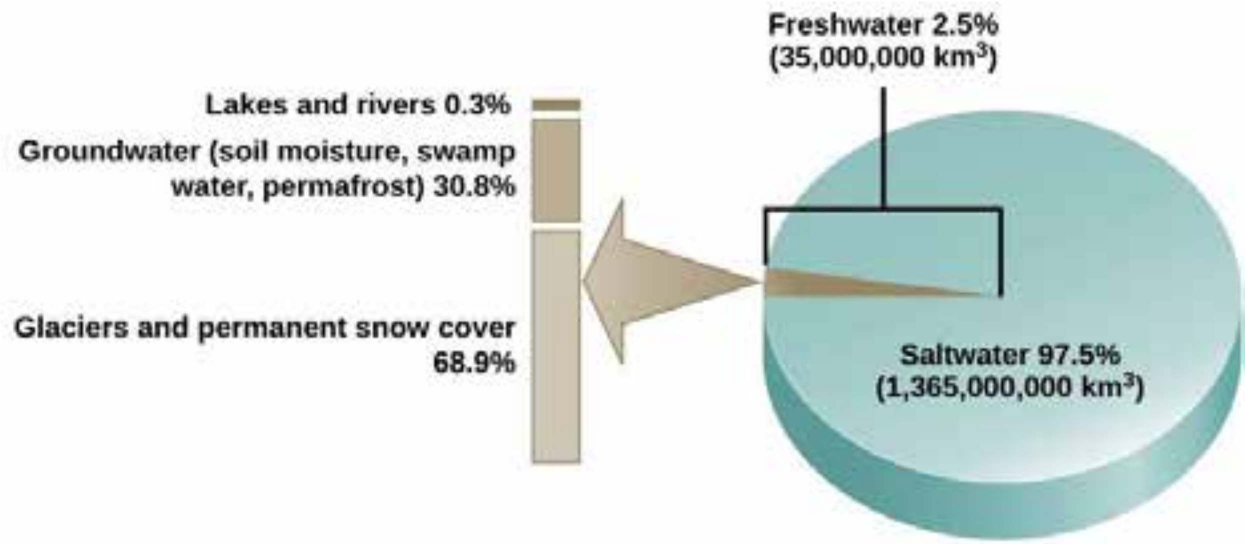


FIGURE 6.9

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

clouds as liquid or frozen droplets and eventually leads to precipitation (rain or snow), which returns water to Earth's surface. Rain reaching Earth's surface may evaporate again, flow over the surface, or percolate into the ground. Most easily observed is surface runoff: the flow of fresh water either from rain or melting ice. Runoff can make its way through streams and lakes to the oceans or flow directly to the oceans themselves.

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

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

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

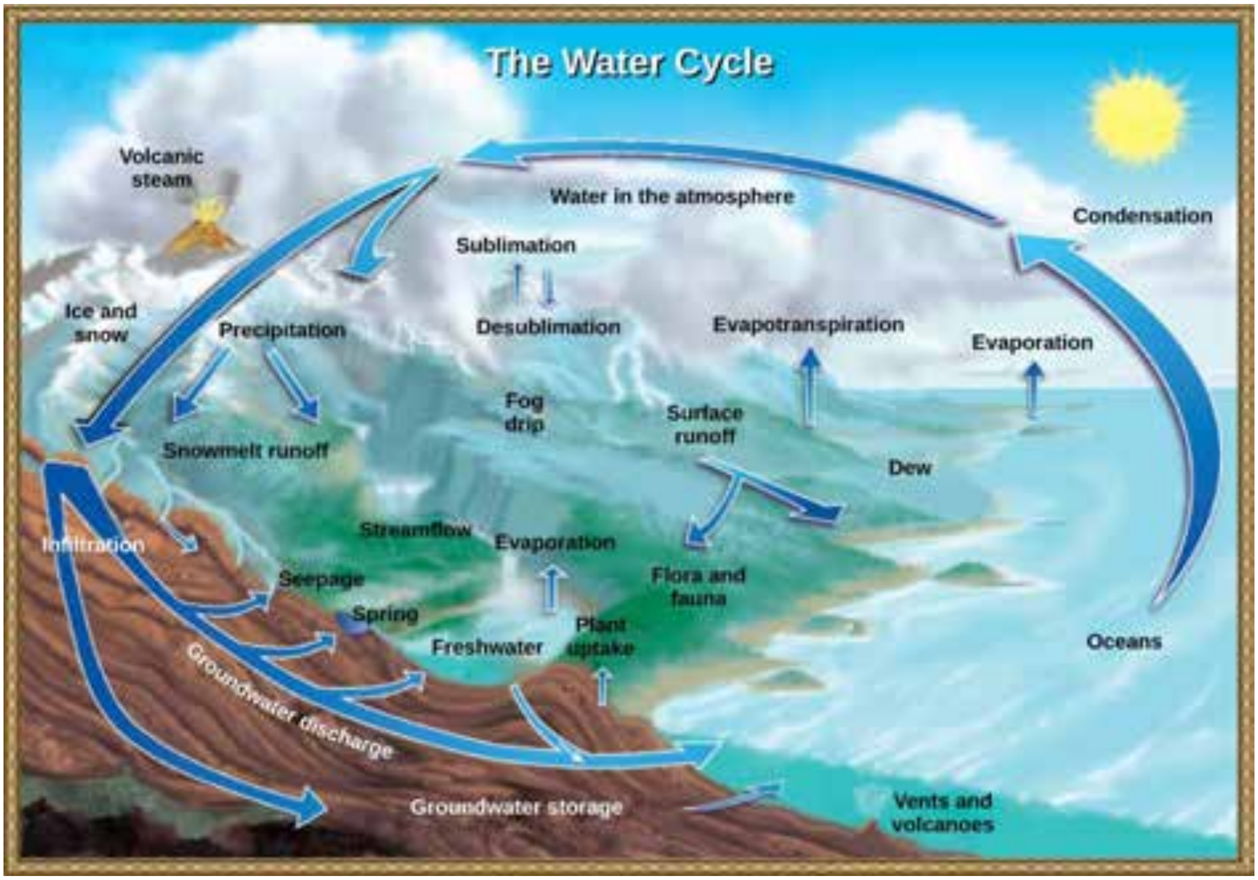


FIGURE 6.10
Water from the land and oceans enters the atmosphere by evaporation or sublimation, where it condenses into clouds and falls as rain or snow. Precipitated water may enter freshwater bodies or infiltrate the soil. The cycle is complete when surface or groundwater reenters the ocean. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

### The Carbon Cycle

Carbon is the fourth most abundant element in living organisms. Carbon is present in all organic molecules, and its role in the structure of macromolecules is of primary importance to living organisms. Carbon compounds contain energy, and many of these compounds from plants and algae have remained stored as fossilized carbon, which humans use as fuel. Since the 1800s, the use of fossil fuels has accelerated. As global demand for Earth's limited fossil fuel supplies has risen since the beginning of the Industrial Revolution, the amount of carbon dioxide in our atmosphere has increased as the fuels are burned. This increase in carbon dioxide has been associated with climate change and is a major environmental concern worldwide.

The carbon cycle is most easily studied as two interconnected subcycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes. The entire carbon cycle is shown in Figure 6.11

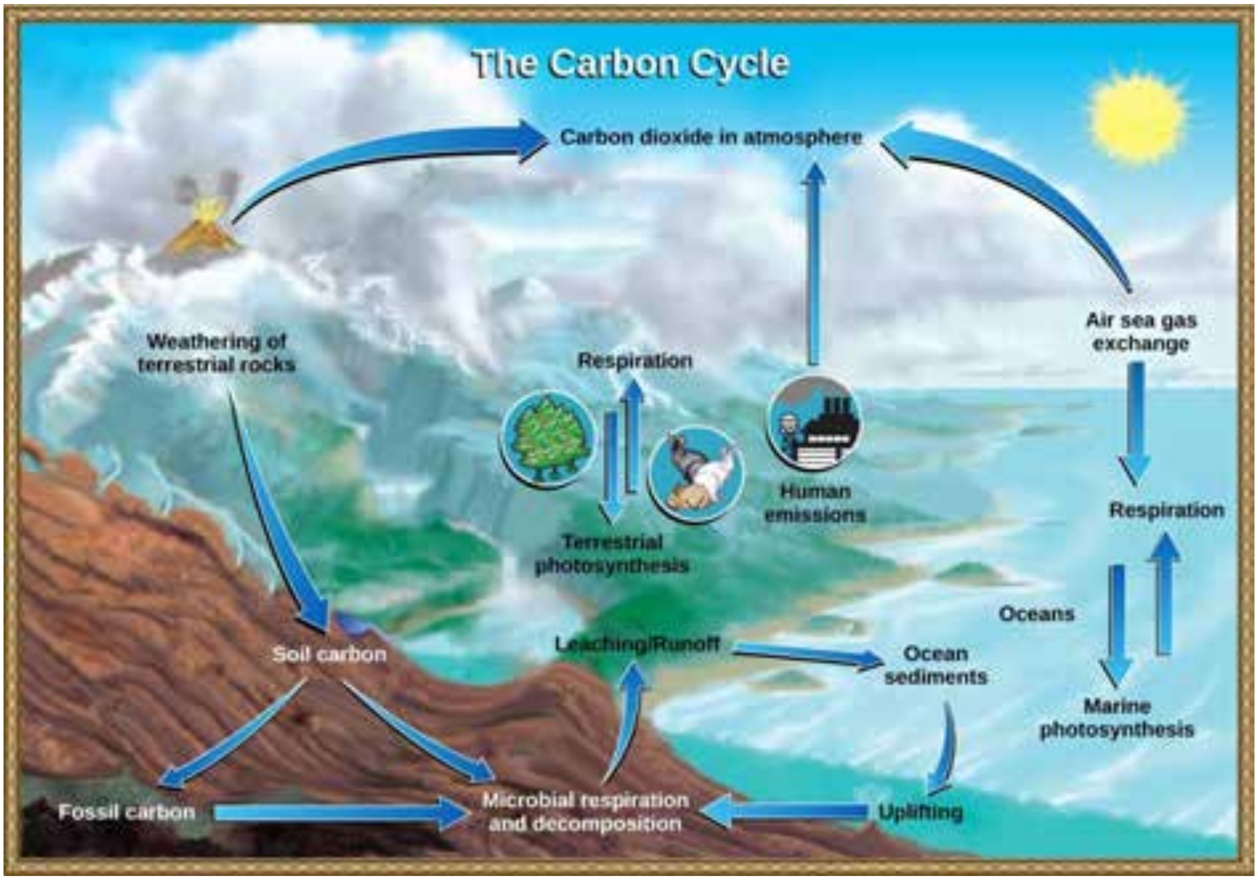


FIGURE 6.11

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

### The Biological Carbon Cycle

Living organisms are connected in many ways, even between ecosystems. A good example of this connection is the exchange of carbon between heterotrophs and autotrophs within and between ecosystems by way of atmospheric carbon dioxide. Carbon dioxide is the basic building block that autotrophs use to build multi-carbon, high-energy compounds, such as glucose. The energy harnessed from the Sun is used by these organisms to form the covalent bonds that link carbon atoms together. These chemical bonds store this energy for later use in the process of respiration. Most terrestrial autotrophs obtain their carbon dioxide directly from the atmosphere, while marine autotrophs acquire it in the dissolved form (carbonic acid, $HCO_3^-$). However the carbon dioxide is acquired, a byproduct of fixing carbon in organic compounds is oxygen. Photosynthetic organisms are responsible for maintaining approximately 21 percent of the oxygen content of the atmosphere that we observe today.

The partners in biological carbon exchange are the heterotrophs (especially the primary consumers, largely herbivores). Heterotrophs acquire the high-energy carbon compounds from the autotrophs by consuming them and breaking them down by respiration to obtain cellular energy, such as ATP. The most efficient type of respiration, aerobic respiration, requires oxygen obtained from the atmosphere or dissolved in water. Thus, there is a constant exchange of oxygen and carbon dioxide between the autotrophs (which need the carbon) and the heterotrophs (which need the oxygen). Autotrophs also respire and consume the organic molecules they form: using oxygen and releasing carbon dioxide. They release more oxygen gas as a waste product of photosynthesis than they use for their own respiration; therefore, there is excess available for the respiration of other aerobic organisms. Gas exchange through the atmosphere and water is one way that the carbon cycle connects all living organisms on Earth.

### The Biogeochemical Carbon Cycle

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

As stated, the atmosphere is a major reservoir of carbon in the form of carbon dioxide that is essential to the process of photosynthesis. The level of carbon dioxide in the atmosphere is greatly influenced by the reservoir of carbon in the oceans. The exchange of carbon between the atmosphere and water reservoirs influences how much carbon is found in each, and each one affects the other reciprocally. Carbon dioxide ($CO_2$) from the atmosphere dissolves in water and, unlike oxygen and nitrogen gas, reacts with water molecules to form ionic compounds. Some of these ions combine with calcium ions in the seawater to form calcium carbonate ($CaCO_3$), a major component of the shells of marine organisms. These organisms eventually form sediments on the ocean floor. Over geologic time, the calcium carbonate forms limestone, which comprises the largest carbon reservoir on Earth.

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

Carbon dioxide is also added to the atmosphere by the animal husbandry practices of humans. The large number of land animals raised to feed Earth's growing human population results in increased carbon-dioxide levels in the atmosphere caused by their respiration. This is another example of how human activity indirectly affects biogeochemical cycles in a significant way. Although much of the debate about the future effects of increasing atmospheric carbon on climate change focuses on fossils fuels, scientists take natural processes, such as volcanoes, plant growth, soil carbon levels, and respiration, into account as they model and predict the future impact of this increase.

### The Nitrogen Cycle

Getting nitrogen into living organisms is difficult. Plants and phytoplankton are not equipped to incorporate nitrogen from the atmosphere (where it exists as tightly bonded, triple covalent $N_2$) even though this molecule comprises approximately 78 percent of the atmosphere. Nitrogen enters the living world through free-living and symbiotic bacteria, which incorporate nitrogen into their macromolecules through specialized biochemical pathways leading to nitrogen fixation. Cyanobacteria live in most aquatic ecosystems where sunlight is present; they play a key role in nitrogen fixation. Cyanobacteria are able to "fix" nitrogen (from nitrogen gas) into ammonia ($NH_3$) that can be incorporated into the macromolecules of the organism. *Rhizobium* bacteria also fix nitrogen and live symbiotically in the root nodules of legumes (such as peas, beans, and peanuts) and provide them with the organic nitrogen they need. Free-living bacteria, such as *Azotobacter*, are also able to fix nitrogen.

Organic nitrogen is especially important to the study of ecosystem dynamics since many ecosystem processes, such as primary production and decomposition, are limited by the available supply of nitrogen. As shown in Figure 6.12, the nitrogen that enters living systems by nitrogen fixation is eventually converted from organic nitrogen back into nitrogen gas by bacteria. This process occurs in three steps in terrestrial systems: ammonification, nitrification, and denitrification. First, the ammonification process converts nitrogenous waste from living animals or from the remains of dead animals into ammonium ($NH_4^+$) by certain bacteria and fungi. Second, this ammonium is then converted to nitrites ($NO_2^-$) by nitrifying bacteria, such as *Nitrosomonas*, through nitrification. Subsequently, nitrites are converted to nitrates ($NO_3^-$) by similar organisms. Lastly, the process of denitrification occurs, whereby bacteria, such as *Pseudomonas* and *Clostridium*, convert the nitrates into nitrogen gas, thus allowing it to re-enter the atmosphere.

**ART CONNECTION**

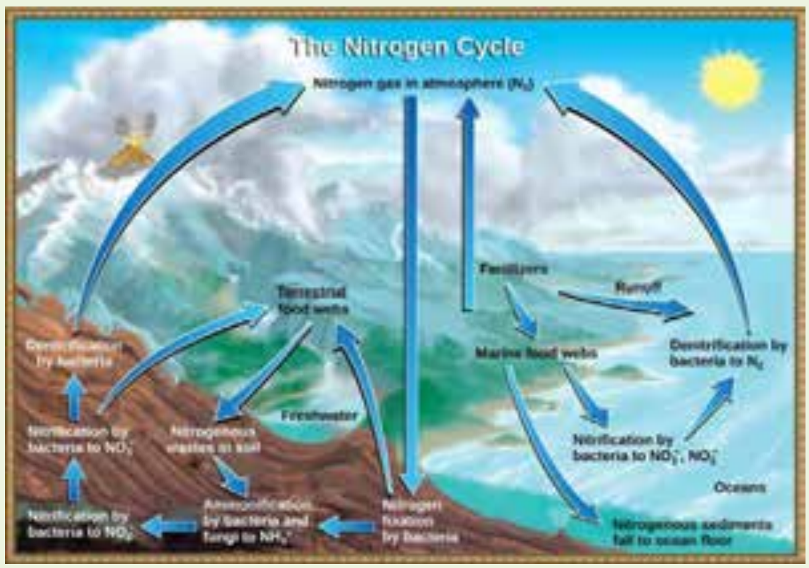


**Figure 4**. Nitrogen enters the living world from the atmosphere through nitrogen-fixing bacteria. This nitrogen and nitrogenous waste from animals is then processed back into gaseous nitrogen by soil bacteria, which also supply terrestrial food webs with the organic nitrogen they need. (credit: modification of work by John M. Evans and Howard Perlman, USGS)

Which of the following statements about the nitrogen cycle is false?

1. Ammonification converts organic nitrogenous matter from living organisms into ammonium ($NH_4^+$).
2. Denitrification by bacteria converts nitrates ($NO_3^-$) to nitrogen gas ($N_2$).
3. Nitrification by bacteria converts nitrates ($NO_3^-$) to nitrites ($NO_2^-$)
4. Nitrogen fixing bacteria convert nitrogen gas ($N_2$) into organic compounds.

Human activity can release nitrogen into the environment by two primary means: the combustion of fossil fuels, which releases different nitrogen oxides, and by the use of artificial fertilizers (which contain nitrogen and phosphorus compounds) in agriculture, which are then washed into lakes, streams, and rivers by surface runoff. Atmospheric nitrogen (other than $N_2$) is associated with several effects on Earth's ecosystems including the production of acid rain (as nitric acid, $HNO_3$) and greenhouse gas effects (as nitrous oxide, $N_2O$), potentially causing climate change. A major effect from fertilizer runoff is saltwater and freshwater eutrophication, a process whereby nutrient runoff causes the overgrowth of algae, the depletion of oxygen and death of aquatic fauna.

A similar process occurs in the marine nitrogen cycle, where the ammonification, nitrification, and denitrification processes are performed by marine bacteria and archaea. Some of this nitrogen falls to the ocean floor as sediment, which can then be moved to land in geologic time by uplift of Earth's surface, and thereby incorporated into terrestrial rock. Although the movement of nitrogen from rock directly into living systems has been traditionally seen as insignificant compared with nitrogen fixed from the atmosphere, a recent study showed that this process may indeed be significant and should be included in any study of the global nitrogen cycle.

### The Phosphorus Cycle

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

Phosphorus occurs in nature as the phosphate ion ($PO_4^{3-}$). In addition to phosphate runoff as a result of human activity, natural surface runoff occurs when it is leached from phosphate-containing rock by weathering, thus sending phosphates into rivers, lakes, and the ocean. This rock has its origins in the ocean. Phosphate-containing ocean sediments form primarily from the bodies of ocean organisms and from their excretions. However, volcanic ash, aerosols, and mineral dust may also be significant phosphate sources. This sediment then is moved to land over geologic time by the uplifting of Earth's surface. (Figure 6.13)

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

Excess phosphorus and nitrogen that enter these ecosystems from fertilizer runoff and from sewage cause excessive growth of algae. The subsequent death and decay of these organisms depletes dissolved oxygen, which leads to the death of aquatic organisms, such as shellfish and finfish. This process is responsible for dead zones in lakes and at the mouths of many major rivers and for massive fish kills, which often occur during the summer months (see Figure 6.14).

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

### The Sulfur Cycle

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

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

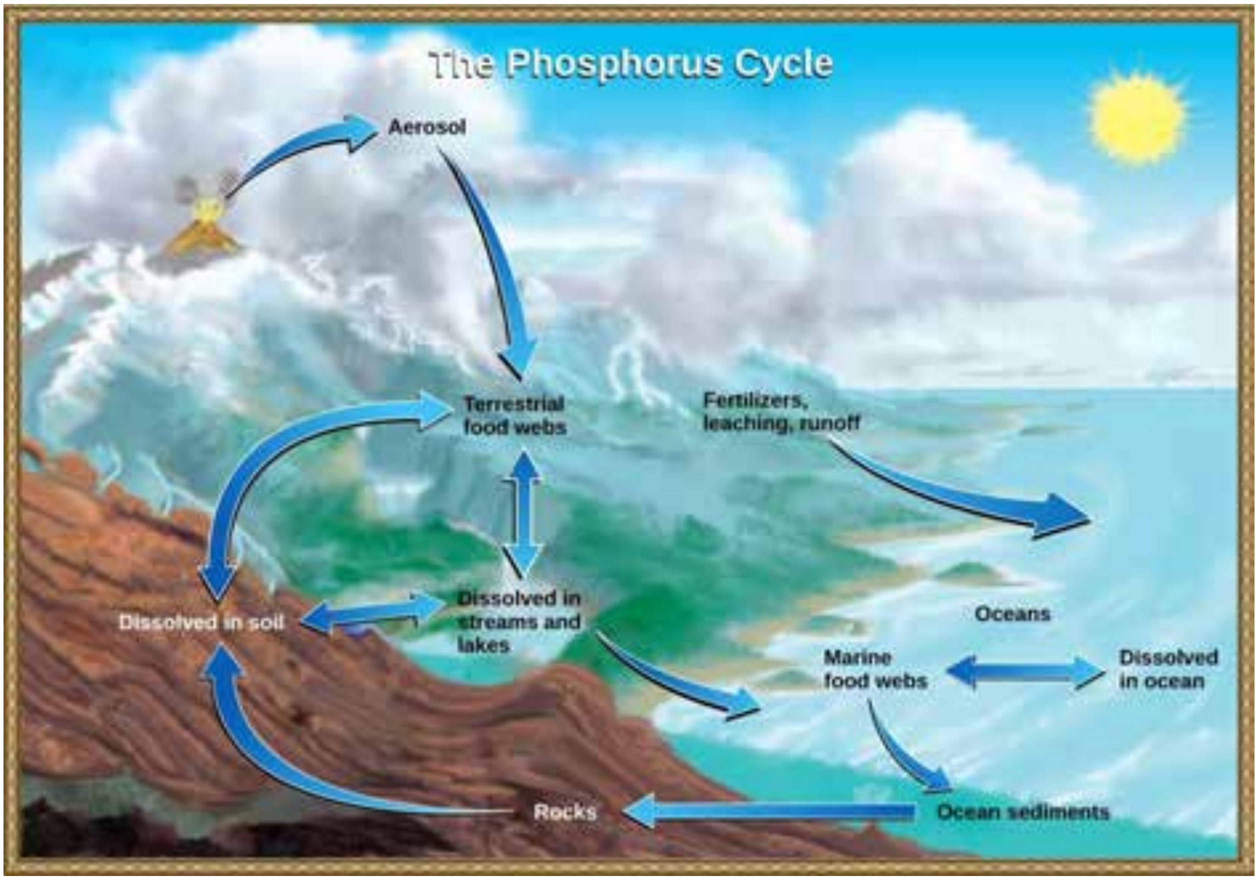


FIGURE 6.12

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

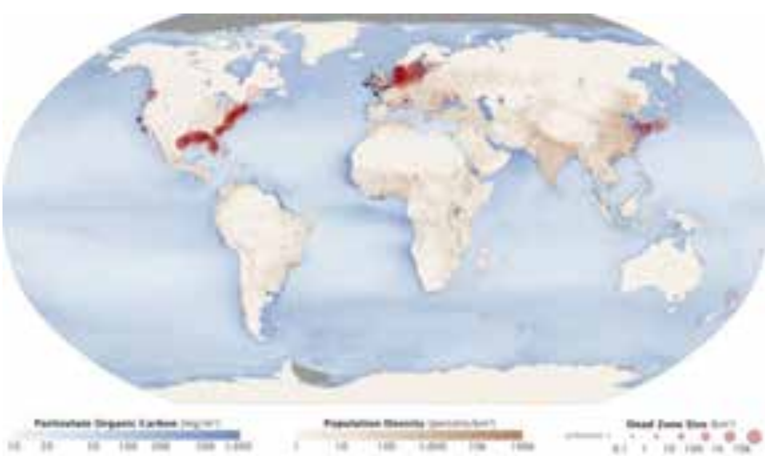

FIGURE 6.13

Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. Worldwide, large dead zones are found in areas of high population density. (credit: Robert Simmon, Jesse Allen, NASA Earth Ob- servatory)

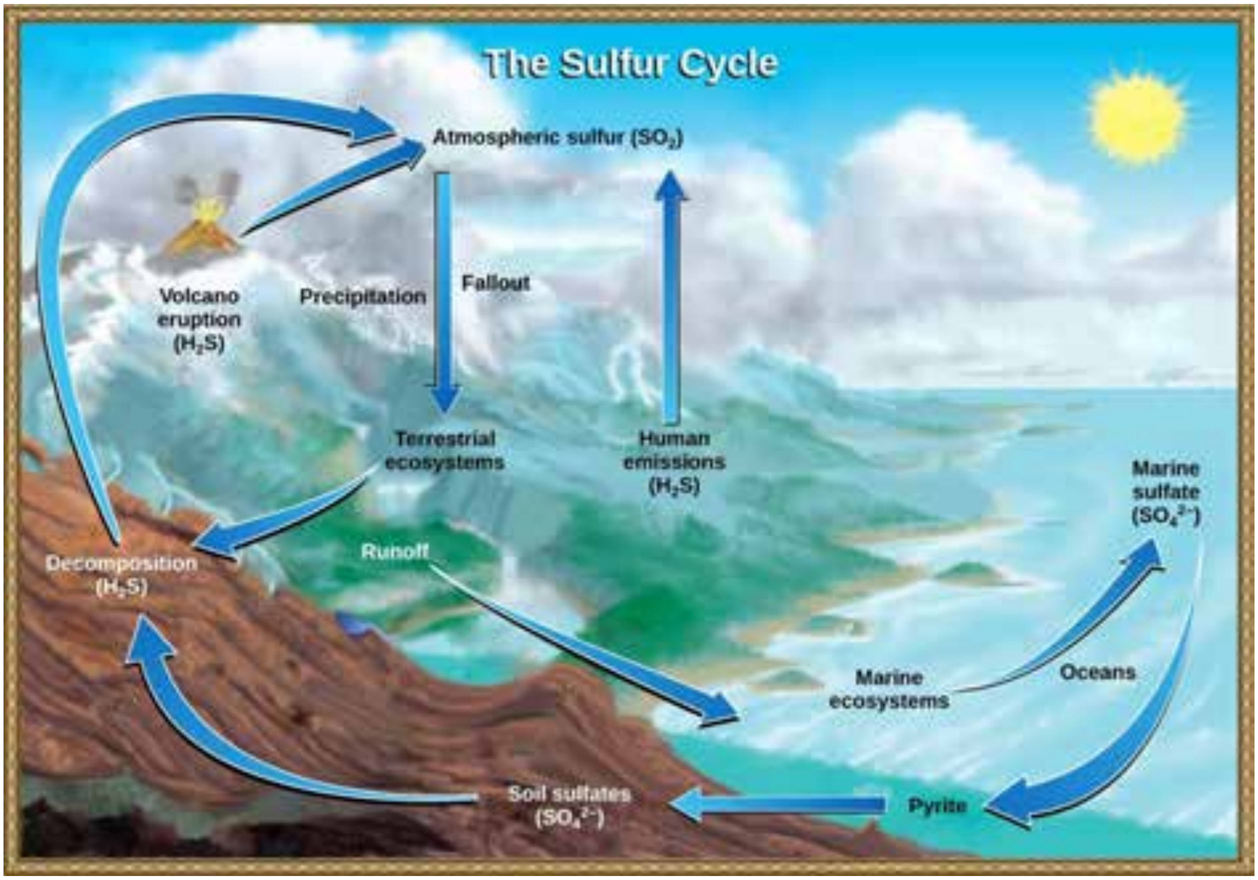


FIGURE 6.14

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

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

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

# 6.3 Terrestrial Biomes

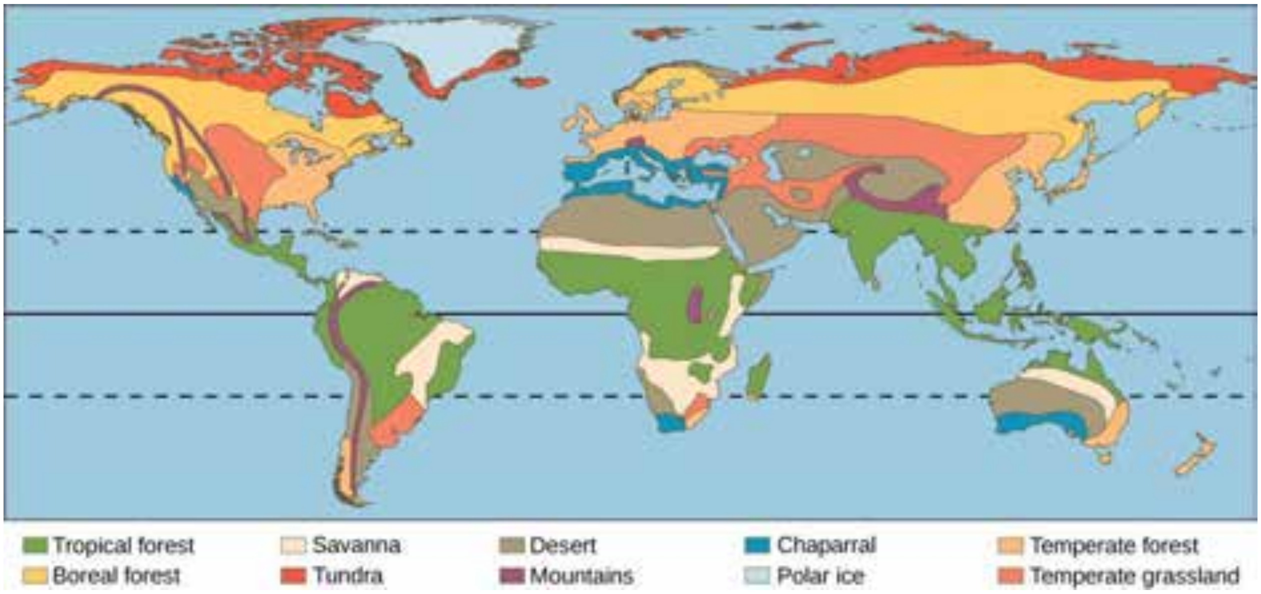


FIGURE 6.15
Each of the world's eight major biomes is distinguished by characteristic temperatures and amount of precipitation. Polar ice caps and mountains are also shown.

Earth's biomes can be either terrestrial or aquatic (OpenStax College, 2013). Terrestrial biomes are based on land, while aquatic biomes include both ocean and freshwater biomes. There are eight major terrestrial biomes: tropical rainforests, savannas, subtropical deserts, chaparral, temperate grasslands, temperate forests, boreal forests, and Arctic tundra. Biomes are distinguished by characteristic temperatures and amount of precipitation. Annual totals and fluctuations of precipitation affect the kinds of vegetation and animal life that can exist in broad geographical regions. Temperature variation on a daily and seasonal basis is also important for predicting the geographic distribution of a biome. Since a biome is defined by climate, the same biome can occur in geographically distinct areas with similar climates (Figure 6.15). There are also large areas on Antarctica, Greenland, and in mountain ranges that are covered by permanent glaciers and support very little life. Strictly speaking, these are not considered biomes and in addition to extremes of cold, they are also often deserts with very low precipitation.

**Tropical rainforests** are also referred to as tropical wet forests. This biome is found in equatorial regions (Figure 1). Tropical rainforests are the most diverse terrestrial biome. This biodiversity is still largely unknown to science and is under extraordinary threat primarily through logging and deforestation for agriculture. Tropical rainforests have also been described as nature's pharmacy because of the potential for new drugs that is largely hidden in the chemicals produced by the huge diversity of plants, animals, and other organisms. The vegetation is characterized by plants with spreading roots and broad leaves that fall off throughout the year, unlike the trees of deciduous forests that lose their leaves in one season. These forests are "evergreen," year-round.

The temperature and sunlight profiles of tropical rainforests are stable in comparison to that of other terrestrial biomes, with average temperatures ranging from 20$^{o}$C to 34$^{o}$C (68$^{o}$F to 93$^{o}$F). Month-to-month temperatures are relatively constant in tropical rainforests, in contrast to forests further from the equator. This lack of temperature seasonality leads to year-round plant growth, rather than the seasonal growth seen in other biomes. In contrast to other ecosystems, a more constant daily amount of sunlight (11–12 hours per day) provides more solar radiation, thereby a longer period of time for plant growth.

The annual rainfall in tropical rainforests ranges from 250 cm to more than 450 cm (8.2–14.8 ft) with considerable seasonal variation. Tropical rainforests have wet months in which there can be more than 30 cm (11–12 in) of precipitation, as well as dry months in which there are fewer than 10 cm (3.5 in) of rainfall. However, the driest month of a tropical rainforest can still exceed the *annual* rainfall of some other biomes, such as deserts.

Tropical rainforests have high net primary productivity because the annual temperatures and precipitation values support rapid plant growth (6.16). However, the high rainfall quickly leaches nutrients from the soils of these forests, which are typically low in nutrients. Tropical rainforests are characterized by vertical layering of vegetation and the formation of distinct habitats for animals within each layer. On the forest floor is a sparse layer of plants and decaying plant matter. Above that is an understory of short, shrubby foliage. A layer of trees rises above this understory and is topped by a closed upper canopy—the uppermost overhead layer of branches and leaves. Some additional trees emerge through this closed upper canopy. These layers provide diverse and complex habitats for the variety of plants, animals, and other organisms within the tropical wet forests. Many species of animals use the variety of plants and the complex structure of the tropical wet forests for food and shelter. Some organisms live several meters above ground rarely ever descending to the forest floor.

Rainforests are not the only forest biome in the tropics; there are also tropical dry forests, which are characterized by a dry season of varying lengths. These forests commonly experience leaf loss during the dry season to one degree or another. The loss of leaves from taller trees during the dry season opens up the canopy and allows sunlight to the forest floor that allows the growth of thick ground-level brush, which is absent in tropical rainforests. Extensive tropical dry forests occur in Africa (including Madagascar), India, southern Mexico, and South America.

FIGURE 6.16
Species diversity is very high in tropical wet forests, such as these forests of Madre de Dios, Peru, near the Amazon River. (credit: Roosevelt Garcia)

**Savannas** are grasslands with scattered trees, and they are found in Africa, South America, and northern Australia (6.17). Savannas are hot, tropical areas with temperatures averaging from 24$^{o}$C –29$^{o}$C (75$^{o}$F –84$^{o}$F) and an annual rainfall of 51–127 cm (20–50 in). Savannas have an extensive dry season and consequent fires. As a result, scattered in the grasses and forbs (herbaceous flowering plants) that dominate the savanna, there are relatively few trees. Since fire is an important source of disturbance in this biome, plants have evolved well-developed root systems that allow them to quickly re-sprout after a fire.

FIGURE 6.17
Although savannas are dominated by grasses, small woodlands, such as this one in Mount Archer National Park in Queensland, Australia, may dot the landscape. (credit: "Ethel Aardvark"/Wikimedia Commons)

**Subtropical deserts** exist between $15^o$ and $30^o$ north and south latitude and are centered on the Tropic of Cancer and the Tropic of Capricorn (6.18). Deserts are frequently located on the downwind or lee side of mountain ranges, which create a rain shadow after prevailing winds drop their water content on the mountains. This is typical of the North American deserts, such as the Mohave and Sonoran deserts. Deserts in other regions, such as the Sahara Desert in northern Africa or the Namib Desert in southwestern Africa are dry because of the high-pressure, dry air descending at those latitudes. Subtropical deserts are very dry; evaporation typically exceeds precipitation. Subtropical hot deserts can have daytime soil surface temperatures above $60^o$C ($140^o$F) and nighttime temperatures approaching $0^o$C ($32^o$F). The temperature drops so far because there is little water vapor in the air to prevent radiative cooling of the land surface. Subtropical deserts are characterized by low annual precipitation of fewer than 30 cm (12 in) with little monthly variation and lack of predictability in rainfall. Some years may receive tiny amounts of rainfall, while others receive more. In some cases, the annual rainfall can be as low as 2 cm (0.8 in) in subtropical deserts located in central Australia ("the Outback") and northern Africa.

The low species diversity of this biome is closely related to its low and unpredictable precipitation. Despite the relatively low diversity, desert species exhibit fascinating adaptations to the harshness of their environment. Very dry deserts lack perennial vegetation that lives from one year to the next; instead, many plants are annuals that grow quickly and reproduce when rainfall does occur, then they die. Perennial plants in deserts are characterized by adaptations that conserve water: deep roots, reduced foliage, and water-storing stems (6.18). Seed plants in the desert produce seeds that can lie dormant for extended periods between rains. Most animal life in subtropical deserts has adapted to a nocturnal life, spending the hot daytime hours beneath the ground. The Namib Desert is the oldest on the planet, and has probably been dry for more than 55 million years. It supports a number of endemic species (species found only there) because of this great age. For example, the unusual gymnosperm *Welwitschia mirabilis* is the only extant species of an entire order of plants. There are also five species of reptiles considered endemic to the Namib.

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

The **chaparral** is also called scrub forest and is found in California, along the Mediterranean Sea, and along the southern coast of Australia 6.19. The annual rainfall in this biome ranges from 65 cm to 75 cm (25.6–29.5 in) and the majority of the rain falls in the winter. Summers are very dry and many chaparral plants are dormant during

FIGURE 6.18
Many desert plants have tiny leaves or no leaves at all to reduce water loss. The leaves of ocotillo, shown here in the Chihuahuan Desert in Big Bend National Park, Texas, appear only after rainfall and then are shed. (credit "bare ocotillo": "Leaflet"/Wikimedia Commons)

the summertime. The chaparral vegetation is dominated by shrubs and is adapted to periodic fires, with some plants producing seeds that germinate only after a hot fire. The ashes left behind after a fire are rich in nutrients like nitrogen that fertilize the soil and promote plant regrowth. Fire is a natural part of the maintenance of this biome and frequently threatens human habitation in this biome in the U.S. (Figure).

FIGURE 6.19
The chaparral is dominated by shrubs. (credit: Miguel Vieira)

**Temperate grasslands** are found throughout central North America, where they are also known as prairies, and in Eurasia, where they are known as steppes (6.20). Temperate grasslands have pronounced annual fluctuations in temperature with hot summers and cold winters. The annual temperature variation produces specific growing seasons for plants. Plant growth is possible when temperatures are warm enough to sustain plant growth, which occurs in the spring, summer, and fall.

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

Fires, which are a natural disturbance in temperate grasslands, can be ignited by lightning strikes. It also appears that the lightning-caused fire regime in North American grasslands was enhanced by intentional burning by humans.

FIGURE 6.20
The American bison (Bison bison), more commonly called the buffalo, is a grazing mammal that once populated American prairies in huge numbers. (credit: Jack Dykinga, USDA ARS)

When fire is suppressed in temperate grasslands, the vegetation eventually converts to scrub and dense forests. Often, the restoration or management of temperate grasslands requires the use of controlled burns to suppress the growth of trees and maintain the grasses.

**Temperate forests** are the most common biome in eastern North America, Western Europe, Eastern Asia, Chile, and New Zealand (Figure 6.22). This biome is found throughout mid-latitude regions. Temperatures range between $-30^{o}$C and $30^{o}$C ($-22^{o}$F to $86^{o}$F) and drop to below freezing on an annual basis. These temperatures mean that temperate forests have defined growing seasons during the spring, summer, and early fall. Precipitation is relatively constant throughout the year and ranges between 75 cm and 150 cm (29.5–59 in).

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

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

The **boreal forest,** also known as taiga or coniferous forest, is found roughly between $50^{o}$ and $60^{o}$ north latitude across most of Canada, Alaska, Russia, and northern Europe (Figure 6.22). Boreal forests are also found above a certain elevation (and below high elevations where trees cannot grow) in mountain ranges throughout the Northern Hemisphere. This biome has cold, dry winters and short, cool, wet summers. The annual precipitation is from 40 cm to 100 cm (15.7–39 in) and usually takes the form of snow; little evaporation occurs because of the cold temperatures.

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

FIGURE 6.21
Deciduous trees are the dominant plant in the temperate forest. (credit: Oliver Herold)

Therefore, coniferous trees that retain nitrogen-rich needles in a nitrogen limiting environment may have had a competitive advantage over the broad-leafed deciduous trees.

The net primary productivity of boreal forests is lower than that of temperate forests and tropical wet forests. The aboveground biomass of boreal forests is high because these slow-growing tree species are long-lived and accumulate standing biomass over time. Species diversity is less than that seen in temperate forests and tropical rainforests. Boreal forests lack the layered forest structure seen in tropical rainforests or, to a lesser degree, temperate forests. The structure of a boreal forest is often only a tree layer and a ground layer. When conifer needles are dropped, they decompose more slowly than broad leaves; therefore, fewer nutrients are returned to the soil to fuel plant growth (Figure 6.22).

FIGURE 6.22
The boreal forest (taiga) has low lying plants and conifer trees. (credit: L.B. Brubaker, NOAA)

The Arctic tundra lies north of the subarctic boreal forests and is located throughout the Arctic regions of the Northern Hemisphere. Tundra also exists at elevations above the tree line on mountains. The average winter temperature is –34˚C (–29.2˚F) and the average summer temperature is 3˚C–12˚C (37˚F –52˚F). Plants in the

Arctic tundra have a short growing season of approximately 50–60 days. However, during this time, there are almost 24 hours of daylight and plant growth is rapid. The annual precipitation of the Arctic tundra is low (15–25 cm or 6–10 in) with little annual variation in precipitation. And, as in the boreal forests, there is little evaporation because of the cold temperatures.

Plants in the Arctic tundra are generally low to the ground and include low shrubs, grasses, lichens, and small flowering plants (Figure 6.23). There is little species diversity, low net primary productivity, and low aboveground biomass. The soils of the Arctic tundra may remain in a perennially frozen state referred to as permafrost. The permafrost makes it impossible for roots to penetrate far into the soil and slows the decay of organic matter, which inhibits the release of nutrients from organic matter. The melting of the permafrost in the brief summer provides water for a burst of productivity while temperatures and long days permit it. During the growing season, the ground of the Arctic tundra can be completely covered with plants or lichens.

FIGURE 6.23
Low-growing plants such as shrub willow dominate the tundra landscape during the summer, shown here in the Arctic National Wildlife Refuge. (credit: Arctic National Wildlife Refuge, USFWS)

# 6.4 Aquatic Biomes

Like terrestrial biomes, aquatic biomes are influenced by abiotic factors. In the case of aquatic biomes the abiotic factors include light, temperature, flow regime, and dissolved solids (OpenStax College, 2013). The aquatic medium—water— has different physical and chemical properties than air. Even if the water in a pond or other body of water is perfectly clear (there are no suspended particles), water, on its own, absorbs light. As one descends deep enough into a body of water, eventually there will be a depth at which the sunlight cannot reach. While there are some abiotic and biotic factors in a terrestrial ecosystem that shade light (like fog, dust, or insect swarms), these are not usually permanent features of the environment. The importance of light in aquatic biomes is central to the communities of organisms found in both freshwater and marine ecosystems because it controls productivity through photosynthesis.

In addition to light, solar radiation warms bodies of water and many exhibit distinct layers of water at differing temperatures. The water temperature affects the organisms' rates of growth and the amount of dissolved oxygen available for respiration.

The movement of water is also important in many aquatic biomes. In rivers, the organisms must obviously be adapted to the constant movement of the water around them, but even in larger bodies of water such as the oceans, regular currents and tides impact availability of nutrients, food resources, and the presence of the water itself.

Finally, all natural water contains dissolved solids, or salts. Fresh water contains low levels of such dissolved substances because the water is rapidly recycled through evaporation and precipitation. The oceans have a relatively constant high salt content. Aquatic habitats at the interface of marine and freshwater ecosystems have complex and variable salt environments that range between freshwater and marine levels. These are known as brackish water environments. Lakes located in closed drainage basins concentrate salt in their waters and can have extremely high salt content that only a few and highly specialized species are able to inhabit.

## Marine Biomes

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

The ocean is categorized by several zones (see Figure 6.25). All of the ocean's open water is referred to as the pelagic realm (or zone). The benthic realm (or zone) extends along the ocean bottom from the shoreline to the deepest parts of the ocean floor. From the surface to the bottom or the limit to which photosynthesis occurs is the photic zone (approximately 200 m or 650 ft). At depths greater than 200 m, light cannot penetrate; thus, this is referred to as the aphotic zone. The majority of the ocean is aphotic and lacks sufficient light for photosynthesis. The deepest part of the ocean, the Challenger Deep (in the Mariana Trench, located in the western Pacific Ocean), is about 11,000 m (about 6.8 mi) deep. To give some perspective on the depth of this trench, the ocean is, on average, 4267 m or 14,000 ft deep.

### Ocean

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

The intertidal zone is the oceanic region that is closest to land. With each tidal cycle, the intertidal zone alternates between being inundated with water and left high and dry. Generally, most people think of this portion of the ocean as a sandy beach. In some cases, the intertidal zone is indeed a sandy beach, but it can also be rocky, muddy, or dense with tangled roots in mangrove forests. The intertidal zone is an extremely variable environment because of tides. Organisms may be exposed to air at low tide and are underwater during high tide. Therefore, living things that thrive in the intertidal zone are often adapted to being dry for long periods of time. The shore of the intertidal zone is also repeatedly struck by waves and the organisms found there are adapted to withstand damage from the pounding action of the waves (see Figure 6.24). The exoskeletons of shoreline crustaceans (such as the shore crab, *Carcinus maenas*) are tough and protect them from desiccation (drying out) and wave damage. Another consequence of the pounding waves is that few algae and plants establish themselves in constantly moving sand or mud.

FIGURE 6.24
Sea stars, sea urchins, and mussel shells are often found in the intertidal zone, shown here in Kachemak Bay, Alaska. (credit: NOAA)

The neritic zone extends from the margin of the intertidal zone to depths of about 200 m (or 650 ft) at the edge of the continental shelf. When the water is relatively clear, photosynthesis can occur in the neritic zone. The water contains silt and is well-oxygenated, low in pressure, and stable in temperature. These factors all contribute to the neritic zone having the highest productivity and biodiversity of the ocean. Phytoplankton, including photosynthetic bacteria and larger species of algae, are responsible for the bulk of this primary productivity. Zooplankton, protists, small fishes, and shrimp feed on the producers and are the primary food source for most of the world's fisheries. The majority of these fisheries exist within the neritic zone.

Beyond the neritic zone is the open ocean area known as the oceanic zone. Within the oceanic zone there is thermal stratification. Abundant phytoplankton and zooplankton support populations of fish and whales. Nutrients are scarce and this is a relatively less productive part of the marine biome. When photosynthetic organisms and the organisms that feed on them die, their bodies fall to the bottom of the ocean where they remain; the open ocean lacks a process for bringing the organic nutrients back up to the surface.

Beneath the pelagic zone is the benthic realm, the deepwater region beyond the continental shelf. The bottom of the benthic realm is comprised of sand, silt, and dead organisms. Temperature decreases as water depth increases. This is a nutrient-rich portion of the ocean because of the dead organisms that fall from the upper layers of the ocean. Because of this high level of nutrients, a diversity of fungi, sponges, sea anemones, marine worms, sea stars, fishes, and bacteria exists.

The deepest part of the ocean is the abyssal zone, which is at depths of 4000 m or greater. The abyssal zone is very cold and has very high pressure, high oxygen content, and low nutrient content. There are a variety of invertebrates and fishes found in this zone, but the abyssal zone does not have photosynthetic organisms. Chemosynthetic bacteria use the hydrogen sulfide and other minerals emitted from deep hydrothermal vents. These chemosynthetic bacteria use the hydrogen sulfide as an energy source and serve as the base of the food chain found around the vents.

**ART CONNECTION**

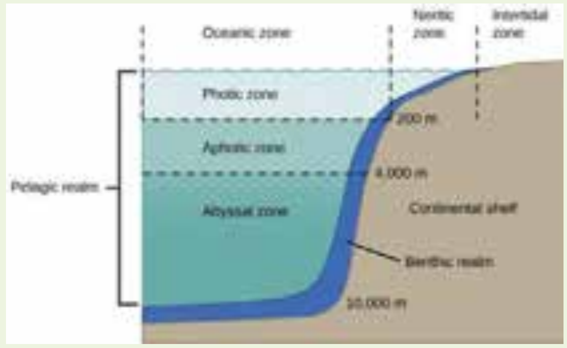


**Figure 2**. The ocean is divided into different zones based on water depth, distance from the shoreline, and light penetration.

Coral reefs

Coral reefs are ocean ridges formed by marine invertebrates living in warm shallow waters within the photic zone of the ocean. They are found within 30° north and south of the equator. The Great Barrier Reef is a well-known reef system located several miles off the northeastern coast of Australia. Other coral reefs are fringing islands, which are directly adjacent to land, or atolls, which are circular reefs surrounding a former island that is now underwater. The coral-forming colonies of organisms (members of phylum Cnidaria) secrete a calcium carbonate skeleton. These calcium-rich skeletons slowly accumulate, thus forming the underwater reef (Figure 6.26). Corals found in shallower waters (at a depth of approximately 60 m or about 200 ft) have a mutualistic relationship with photosynthetic unicellular protists. The relationship provides corals with the majority of the nutrition and the energy they require. The waters in which these corals live are nutritionally poor and, without this mutualism, it would not be possible for large corals to grow because there are few planktonic organisms for them to feed on. Some corals living in deeper and colder water do not have a mutualistic relationship with protists; these corals must obtain their energy exclusively by feeding on plankton using stinging cells on their tentacles. Coral reefs are one of the most diverse biomes. It is estimated that more than 4000 fish species inhabit coral reefs. These fishes can feed on coral, the cryptofauna (invertebrates found within the calcium carbonate structures of the coral reefs), or the seaweed and algae that are associated with the coral. These species include predators, herbivores, or planktivores. Predators are animal species that hunt and are carnivores or "flesh eaters." Herbivores eat plant material, and planktivores eat plankton.

FIGURE 6.25

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

**EVOLUTION IN ACTION**

Global Decline of Coral ReefsIt takes a long time to build a coral reef. The animals that create coral reefs do so over thousands of years, continuing to slowly deposit the calcium carbonate that forms their characteristic ocean homes. Bathed in warm tropical waters, the coral animals and their symbiotic protist partners evolved to survive at the upper limit of ocean water temperature.

Together, climate change and human activity pose dual threats to the long-term survival of the world's coral reefs. The main cause of killing of coral reefs is warmer-than-usual surface water. As global warming raises ocean temperatures, coral reefs are suffering. The excessive warmth causes the coral organisms to expel their endosymbiotic, food-producing protists, resulting in a phenomenon known as bleaching. The colors of corals are a result of the particular protist endosymbiont, and when the protists leave, the corals lose their color and turn white, hence the term "bleaching."

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

When a coral reef begins to die, species diversity plummets as animals lose food and shelter. Coral reefs are also economically important tourist destinations, so the decline of coral reefs poses a serious threat to coastal economies. Human population growth has damaged corals in other ways, too. As human coastal populations increase, the runoff of sediment and agricultural chemicals has increased, causing some of the once-clear tropical waters to become cloudy. At the same time, overfishing of popular fish species has allowed the predator species that eat corals to go unchecked.

### Estuaries

Estuaries are biomes that occur where a river, a source of fresh water, meets the ocean. Therefore, both fresh water and salt water are found in the same vicinity; mixing results in a diluted (brackish) salt water. Estuaries form protected areas where many of the offspring of crustaceans, mollusks, and fish begin their lives. Salinity is an important factor that influences the organisms and the adaptations of the organisms found in estuaries. The salinity of estuaries varies and is based on the rate of flow of its freshwater sources. Once or twice a day, high tides bring salt water into the estuary. Low tides occurring at the same frequency reverse the current of salt water (Figure 6.26).

FIGURE 6.26
As estuary is where fresh water and salt water meet, such as the mouth of the Klamath River in California, shown here. (credit: U.S. Army Corps of Engineers)

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

## Freshwater Biomes

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

### Lakes and Ponds

Lakes and ponds can range in area from a few square meters to thousands of square kilometers. Temperature is an important abiotic factor affecting living things found in lakes and ponds. During the summer in temperate regions, thermal stratification of deep lakes occurs when the upper layer of water is warmed by the Sun and does not mix with deeper, cooler water. The process produces a sharp transition between the warm water above and cold water beneath. The two layers do not mix until cooling temperatures and winds break down the stratification and the water in the lake mixes from top to bottom. During the period of stratification, most of the productivity occurs in the warm, well-illuminated, upper layer, while dead organisms slowly rain down into the cold, dark layer below where decomposing bacteria and cold-adapted species such as lake trout exist. Like the ocean, lakes and ponds have a photic layer in which photosynthesis can occur. Phytoplankton (algae and cyanobacteria) are found here and provide the base of the food web of lakes and ponds. Zooplankton, such as rotifers and small crustaceans, consume these phytoplankton. At the bottom of lakes and ponds, bacteria in the aphotic zone break down dead organisms that sink to the bottom.

Nitrogen and particularly phosphorus are important limiting nutrients in lakes and ponds. Therefore, they are determining factors in the amount of phytoplankton growth in lakes and ponds. When there is a large input of nitrogen and phosphorus (e.g., from sewage and runoff from fertilized lawns and farms), the growth of algae skyrockets, resulting in a large accumulation of algae called an algal bloom. Algal blooms (Figure6.27) can become so extensive that they reduce light penetration in water. As a result, the lake or pond becomes aphotic and photosynthetic plants cannot survive. When the algae die and decompose, severe oxygen depletion of the water occurs. Fishes and other organisms that require oxygen are then more likely to die.

FIGURE 6.27
The uncontrolled growth of algae in this waterway has resulted in an algal bloom.

**Rivers and Streams**

Rivers and the narrower streams that feed into the rivers are continuously moving bodies of water that carry water from the source or headwater to the mouth at a lake or ocean. The largest rivers include the Nile River in Africa, the Amazon River in South America, and the Mississippi River in North America (Figure 6.28).

FIGURE 6.28
Rivers range from (a) narrow and shallow to (b) wide and slow moving. (credit a: modification of work by Cory Zanker; credit b: modification of work by David DeHetre)

Abiotic features of rivers and streams vary along the length of the river or stream. Streams begin at a point of origin referred to as source water. The source water is usually cold, low in nutrients, and clear. The channel (the width of the river or stream) is narrower here than at any other place along the length of the river or stream. Headwater streams are of necessity at a higher elevation than the mouth of the river and often originate in regions with steep grades leading to higher flow rates than lower elevation stretches of the river.

Faster-moving water and the short distance from its origin results in minimal silt levels in headwater streams; therefore, the water is clear. Photosynthesis here is mostly attributed to algae that are growing on rocks; the swift current inhibits the growth of phytoplankton. Photosynthesis may be further reduced by tree cover reaching over the narrow stream. This shading also keeps temperatures lower. An additional input of energy can come from leaves or other organic material that falls into a river or stream from the trees and other plants that border the water. When the leaves decompose, the organic material and nutrients in the leaves are returned to the water. The leaves also support a food chain of invertebrates that eat them and are in turn eaten by predatory invertebrates and fish. Plants and animals have adapted to this fast-moving water. For instance, leeches (phylum Annelida) have elongated bodies and suckers on both ends. These suckers attach to the substrate, keeping the leech anchored in place. In temperate regions, freshwater trout species (phylum Chordata) may be an important predator in these fast-moving and colder river and streams.

As the river or stream flows away from the source, the width of the channel gradually widens, the current slows, and the temperature characteristically increases. The increasing width results from the increased volume of water from more and more tributaries. Gradients are typically lower farther along the river, which accounts for the slowing flow. With increasing volume can come increased silt, and as the flow rate slows, the silt may settle, thus increasing the deposition of sediment. Phytoplankton can also be suspended in slow-moving water. Therefore, the water will not be as clear as it is near the source. The water is also warmer as a result of longer exposure to sunlight and the absence of tree cover over wider expanses between banks. Worms (phylum Annelida) and insects (phylum Arthropoda) can be found burrowing into the mud. Predatory vertebrates (phylum Chordata) include waterfowl, frogs, and fishes. In heavily silt-laden rivers, these predators must find food in the murky waters, and, unlike the trout in the clear waters at the source, these vertebrates cannot use vision as their primary sense to find food. Instead, they are more likely to use taste or chemical cues to find prey.

When a river reaches the ocean or a large lake, the water typically slows dramatically and any silt in the river water will settle. Rivers with high silt content discharging into oceans with minimal currents and wave action will build deltas, low-elevation areas of sand and mud, as the silt settles onto the ocean bottom. Rivers with low silt content or in areas where ocean currents or wave action are high create estuarine areas where the fresh water and salt water mix.

**Wetlands**

Wetlands are environments in which the soil is either permanently or periodically saturated with water. Wetlands are different from lakes and ponds because wetlands exhibit a near continuous cover of emergent vegetation. Emergent vegetation consists of wetland plants that are rooted in the soil but have portions of leaves, stems, and flowers extending above the water's surface. There are several types of wetlands including marshes, swamps, bogs, mudflats, and salt marshes (Figure 6.29).

FIGURE 6.29

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

Freshwater marshes and swamps are characterized by slow and steady water flow. Bogs develop in depressions where water flow is low or nonexistent. Bogs usually occur in areas where there is a clay bottom with poor percolation. Percolation is the movement of water through the pores in the soil or rocks. The water found in a bog is stagnant and oxygen depleted because the oxygen that is used during the decomposition of organic matter is not replaced. As the oxygen in the water is depleted, decomposition slows. This leads to organic acids and other acids building up and lowering the pH of the water. At a lower pH, nitrogen becomes unavailable to plants. This creates a challenge for plants because nitrogen is an important limiting resource. Some types of bog plants (such as sundews, pitcher plants, and Venus flytraps) capture insects and extract the nitrogen from their bodies. Bogs have low net primary productivity because the water found in bogs has low levels of nitrogen and oxygen.

# 6.5 Resources

## Summary

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

## Review Questions

1. Describe the basic types of ecosystems on Earth.
2. Explain how the efficiency of energy transfers between trophic levels effects ecosystem.
3. Describe how organisms acquire energy in a food web and in associated food chains.
4. Explain how human activities have impacted biogeochemical cycles and the resulting potential consequences for Earth.
5. Compare grazing and detrital food webs. Why would they both be present in the same ecosystem?
6. The extremely low precipitation of subtropical desert biomes might lead one to expect fire to be a major disturbance factor; however, fire is more common in the temperate grassland biome than in the subtropical desert biome. Why is this?
7. In what ways are the subtropical desert and the Arctic tundra similar?

# 6.6. References

OpenStax College. (2013). *Concepts of biology*. Retrieved from http://cnx.org/contents/b3c1e1d2-839c-42b0-a314- e119a8aafbdd@8.10. OpenStax CNX. Available under Creative Commons Attribution License 3.0 (CC BY 3.0). Modified from original.

# CHAPTER 7 Community and Population Ecology

## Chapter Outline



FIGURE 7.1

Asian carp jump out of the water in response to electrofishing.

## Learning Outcomes

After studying this chapter, you should be able to:

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

# 7.1 Population Dynamics and Demographics

## Introduction

Imagine sailing down a river in a small motorboat on a weekend afternoon; the water is smooth, and you are enjoying the sunshine and cool breeze when suddenly you are hit in the head by a 20-pound silver carp (OpenStax College, 2013). This is a risk now on many rivers and canal systems in Illinois and Missouri because of the presence of Asian carp. This fish—actually a group of species including the silver, black, grass, and big head carp—has been farmed and eaten in China for over 1,000 years. It is one of the most important aquaculture food resources worldwide. In the United States, however, Asian carp is considered a dangerous invasive species that disrupts ecological community structure to the point of threatening native species. The effects of invasive species (such as the Asian carp, kudzu vine, predatory snakehead fish, and zebra mussel) are just one aspect of what ecologists study to understand how populations interact within ecological communities, and what impact natural and human-induced disturbances have on the characteristics of communities.

## Population Size and Density

Population is a group of organisms of the same species that live in the same area. The size and composition of a population fluctuate in response to numerous factors, including seasonal and yearly changes in the environment, natural disasters such as forest fires and volcanic eruptions, and competition for resources between and within species. The statistical study of populations is called demography: a set of mathematical tools designed to describe populations and investigate how they change. Many of these tools were actually designed to study human populations. For example, life tables, which detail the life expectancy of individuals within a population, were initially developed by life insurance companies to set insurance rates. In fact, while the term "demographics" is sometimes assumed to mean a study of human populations, all living populations can be studied using this approach.

Populations are characterized by their population size (total number of individuals) and their population density (number of individuals per unit area). A population may have a large number of individuals that are distributed densely, or sparsely. There are also populations with small numbers of individuals that may be dense or very sparsely distributed in a local area. Population size can affect potential for adaptation because it affects the amount of genetic variation present in the population. Density can have effects on interactions within a population such as competition for food and the ability of individuals to find a mate. Smaller organisms tend to be more densely distributed than larger organisms (Figure 7.2).

### Estimating Population Size

The most accurate way to determine population size is to count all of the individuals within the area. However, this method is usually not logistically or economically feasible, especially when studying large areas. Thus, scientists usually study populations by sampling a representative portion of each habitat and use this sample to make inferences about the population as a whole. The methods used to sample populations to determine their size and density are typically tailored to the characteristics of the organism being studied. For immobile organisms such as plants, or for very small and slow-moving organisms, a **quadrat** may be used. A quadrat is a wood, plastic, or metal square that is randomly located on the ground and used to count the number of individuals that lie within its boundaries. To obtain an accurate count using this method, the square must be placed at random locations within the habitat enough times to produce an accurate estimate. This counting method will provide an estimate of both population size and density. The number and size of quadrat samples depends on the type of organisms and the nature of their distribution.

For smaller mobile organisms, such as mammals, a technique called **mark and recapture** is often used. This method

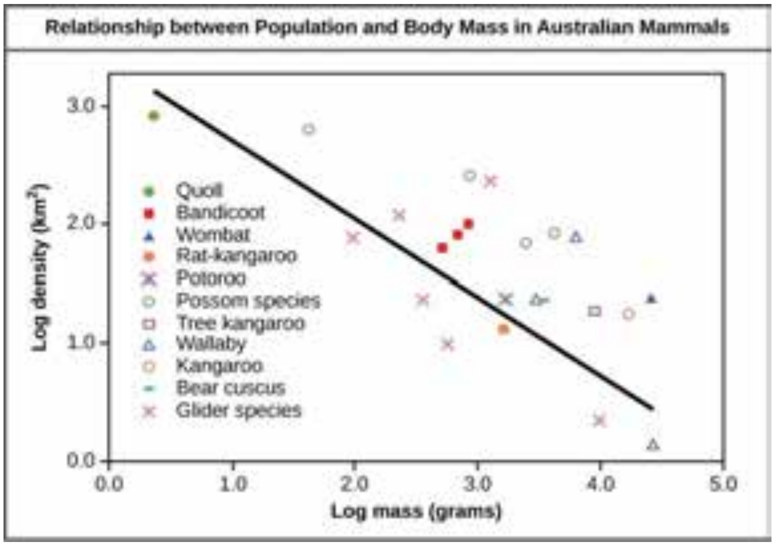


FIGURE 7.2
Australian mammals show a typical inverse relationship between population density and body size. As this graph shows, population density typically decreases with increasing body size. Why do you think this is the case?

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

$$\frac{\text{number marked first catch} \times \text{total number second catch}}{\text{number marked second catch}} = N$$

Using our example, the population size would be 400.

$$\frac{80 \times 100}{20} = 400$$

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

**Species Distribution**

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

Individuals within a population can be distributed at random, in groups, or equally spaced apart (more or less). These are known as **random**, **clumped**, and **uniform** distribution patterns, respectively (Figure7.3). Different distributions reflect important aspects of the biology of the species; they also affect the mathematical methods required to estimate population sizes. An example of **random** distribution occurs with dandelion and other plants that have wind-dispersed seeds that germinate wherever they happen to fall in favorable environments. A **clumped** distribution, may be seen in plants that drop their seeds straight to the ground, such as oak trees; it can also be seen in animals that live in social groups (schools of fish or herds of elephants). **Uniform** distribution is observed in plants that secrete substances inhibiting the growth of nearby individuals (such as the release of toxic chemicals by sage plants). It is also seen in territorial animal species, such as penguins that maintain a defined territory for nesting. The territorial defensive behaviors of each individual create a regular pattern of distribution of similar-sized territories and individuals within those territories. Thus, the distribution of the individuals within a population provides more information about how they interact with each other than does a simple density measurement. Just as lower density species might have more difficulty finding a mate, solitary species with a random distribution might have a similar difficulty when compared to social species clumped together in groups.

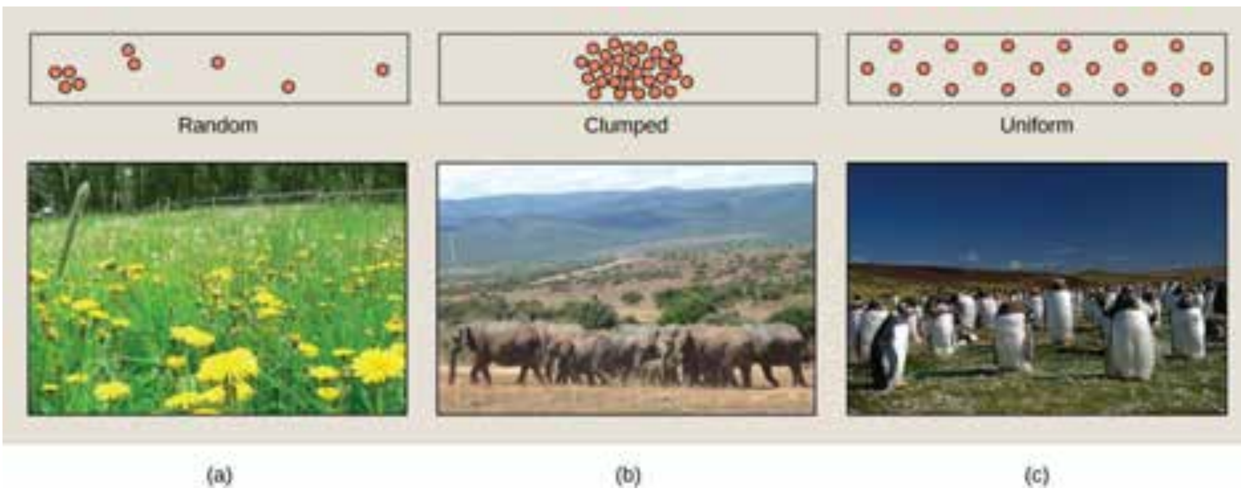


FIGURE 7.3

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

**Demography**

While population size and density describe a population at one particular point in time, scientists must use **demography** to study the dynamics of a population. Demography is the statistical study of population changes over time: birth rates, death rates, and life expectancies. These population characteristics are often displayed in a life table (OpenStax College, 2013).

Life tables provide important information about the life history of an organism and the life expectancy of individuals at each age. They are modeled after actuarial tables used by the insurance industry for estimating human life expectancy. Life tables may include the probability of each age group dying before their next birthday, the percentage of surviving individuals dying at a particular age interval (their mortality rate, and their life expectancy at each interval. An example of a life table is shown in Tablefrom a study of Dall mountain sheep, a species native to northwestern North America. Notice that the population is divided into age intervals (column A). The mortality rate (per 1000) shown in column D is based on the number of individuals dying during the age interval (column B), divided by the number of individuals surviving at the beginning of the interval (Column C) multiplied by 1000.

$$\text{mortality rate} = \frac{\text{number of individuals dying}}{\text{number of individuals surviving}} \times 1000$$

For example, between ages three and four, 12 individuals die out of the 776 that were remaining from the original 1000 sheep. This number is then multiplied by 1000 to give the mortality rate per thousand.

$$\text{mortality rate} = \frac{12}{776} \times 1000 \approx 15.5$$

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

**Life Table of Dall Mountain Sheep**

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

This life table of Ovis dalli shows the number of deaths, number of survivors, mortality rate, and life expectancy at each age interval for Dall mountain sheep.

**Survivorship curves**

Another tool used by population ecologists is a **survivorship curve**, which is a graph of the number of individuals surviving at each age interval versus time. These curves allow us to compare the life histories of different populations

(Figure 7.4). There are three types of survivorship curves. In a type I curve, mortality is low in the early and middle years and occurs mostly in older individuals. Organisms exhibiting a **type I survivorship** typically produce few offspring and provide good care to the offspring increasing the likelihood of their survival. Humans and most mammals exhibit a type I survivorship curve. In type II curves, mortality is relatively constant throughout the entire life span, and mortality is equally likely to occur at any point in the life span.

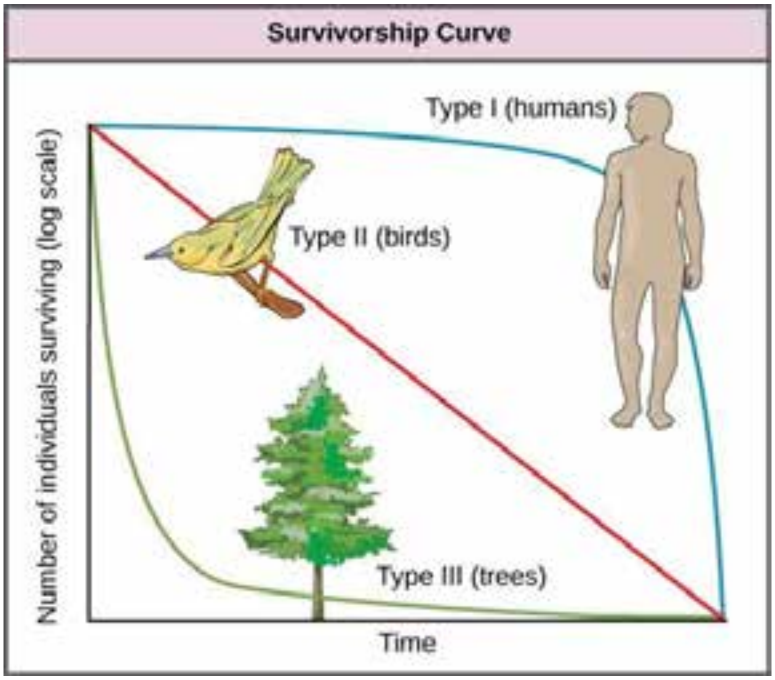


FIGURE 7.4
Survivorship curves show the distribution of individuals in a population according to age. Humans and most mammals have a Type I survivorship curve, because death primarily occurs in the older years. Birds have a Type II survivorship curve, as death at any age is equally probable. Trees have a Type III survivorship curve because very few survive the younger years, but after a certain age, individuals are much more likely to survive.

Many bird populations provide examples of an intermediate or **type II survivorship** curve. In **type III survivorship** curves, early ages experience the highest mortality with much lower mortality rates for organisms that make it to advanced years. Type III organisms typically produce large numbers of offspring, but provide very little or no care for them. Trees and marine invertebrates exhibit a type III survivorship curve because very few of these organisms survive their younger years, but those that do make it to an old age are more likely to survive for a relatively long period of time.

# 7.2 Population Growth & Regulation

Population ecologists make use of a variety of methods to model population dynamics (OpenStax College, 2013). An accurate model should be able to describe the changes occurring in a population and predict future changes.

### Population Growth

The two simplest models of population growth use deterministic equations (equations that do not account for random events) to describe the rate of change in the size of a population over time. The first of these models, **exponential growth**, describes theoretical populations that increase in numbers without any limits to their growth. The second model, **logistic growth**, introduces limits to reproductive growth that become more intense as the population size increases. Neither model adequately describes natural populations, but they provide points of comparison.

### Exponential Growth

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

The best example of exponential growth in organisms is seen in bacteria. Bacteria are prokaryotes that reproduce largely by binary fission. This division takes about an hour for many bacterial species. If 1000 bacteria are placed in a large flask with an abundant supply of nutrients (so the nutrients will not become quickly depleted), the number of bacteria will have doubled from 1000 to 2000 after just an hour. In another hour, each of the 2000 bacteria will divide, producing 4000 bacteria. After the third hour, there should be 8000 bacteria in the flask. The important concept of exponential growth is that the growth rate—the number of organisms added in each reproductive generation—is itself increasing; that is, the population size is increasing at a greater and greater rate. After 24 of these cycles, the population would have increased from 1000 to more than 16 billion bacteria. When the population size, $N$, is plotted over time, a **J-shaped growth curve** is produced (Figure 7.5).

The bacteria-in-a-flask example is not truly representative of the real world where resources are usually limited. However, when a species is introduced into a new habitat that it finds suitable, it may show exponential growth for a while. In the case of the bacteria in the flask, some bacteria will die during the experiment and thus not reproduce; therefore, the growth rate is lowered from a maximal rate in which there is no mortality. The growth rate of a population is largely determined by subtracting the **death rate**, $D$, (number organisms that die during an interval) from the **birth rate**, $B$, (number organisms that are born during an interval). The growth rate can be expressed in a simple equation that combines the birth and death rates into a single factor: $r$. This is shown in the following formula:

**Population growth = rN**

## Logistic Growth

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

### Carrying Capacity and the Logistic Model

In the real world, with its limited resources, exponential growth cannot continue indefinitely. Exponential growth may occur in environments where there are few individuals and plentiful resources, but when the number of individuals gets large enough, resources will be depleted and the growth rate will slow down. Eventually, the growth rate will plateau or level off (Figure 7.5). This population size, which is determined by the maximum population size that a particular environment can sustain, is called the **carrying capacity,** or K. In real populations, a growing population often overshoots its carrying capacity, and the death rate increases beyond the birth rate causing the population size to decline back to the carrying capacity or below it. Most populations usually fluctuate around the carrying capacity in an undulating fashion rather than existing right at it.

The formula used to calculate logistic growth adds the carrying capacity as a moderating force in the growth rate. The expression "K – N" is equal to the number of individuals that may be added to a population at a given time, and "K – N" divided by "K" is the fraction of the carrying capacity available for further growth. Thus, the exponential growth model is restricted by this factor to generate the logistic growth equation:

$$Population growth = rN \left( \frac{K-N}{K} \right)$$

Notice that when N is almost zero the quantity in brackets is almost equal to 1 (or K/K) and growth is close to exponential. When the population size is equal to the carrying capacity, or N = K, the quantity in brackets is equal to zero and growth is equal to zero. A graph of this equation (logistic growth) yields the S-shaped curve (Figure 7.5). It is a more realistic model of population growth than exponential growth. There are three different sections to an S-shaped curve. Initially, growth is exponential because there are few individuals and ample resources available. Then, as resources begin to become limited, the growth rate decreases. Finally, the growth rate levels off at the carrying capacity of the environment, with little change in population number over time.

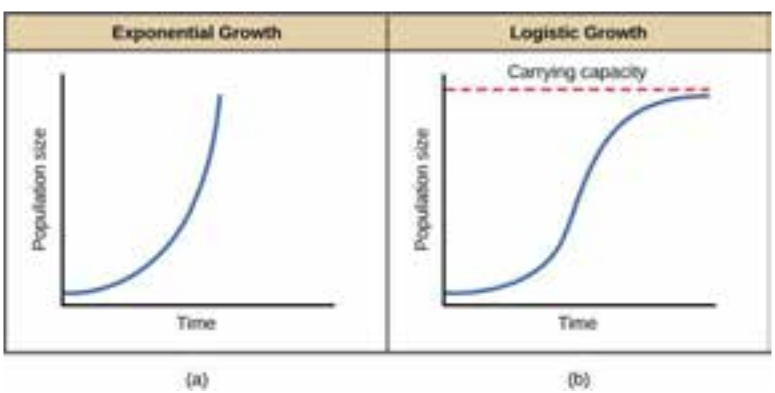


FIGURE 7.5

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

### Role of Intraspecific Competition

The logistic model assumes that every individual within a population will have equal access to resources and, thus, an equal chance for survival. For plants, the amount of water, sunlight, nutrients, and space to grow are the important resources, whereas in animals, important resources include food, water, shelter, nesting space, and mates.

In the real world, phenotypic variation among individuals within a population means that some individuals will be better adapted to their environment than others. The resulting competition for resources among population members of the same species is termed **intraspecific competition**. Intraspecific competition may not affect populations that are well below their carrying capacity, as resources are plentiful and all individuals can obtain what they need. However, as population size increases, this competition intensifies. In addition, the accumulation of waste products can reduce carrying capacity in an environment.

## Examples of Logistic Growth

Yeast, a microscopic fungus used to make bread and alcoholic beverages, exhibits the classical S-shaped curve when grown in a test tube (Figure 7.6). Its growth levels off as the population depletes the nutrients that are necessary for its growth. In the real world, however, there are variations to this idealized curve. Examples in wild populations include sheep and harbor seals (Figure 7.6). In both examples, the population size exceeds the carrying capacity for short periods of time and then falls below the carrying capacity afterwards. This fluctuation in population size continues to occur as the population oscillates around its carrying capacity. Still, even with this oscillation, the logistic model is confirmed.

## Population Dynamics and Regulation

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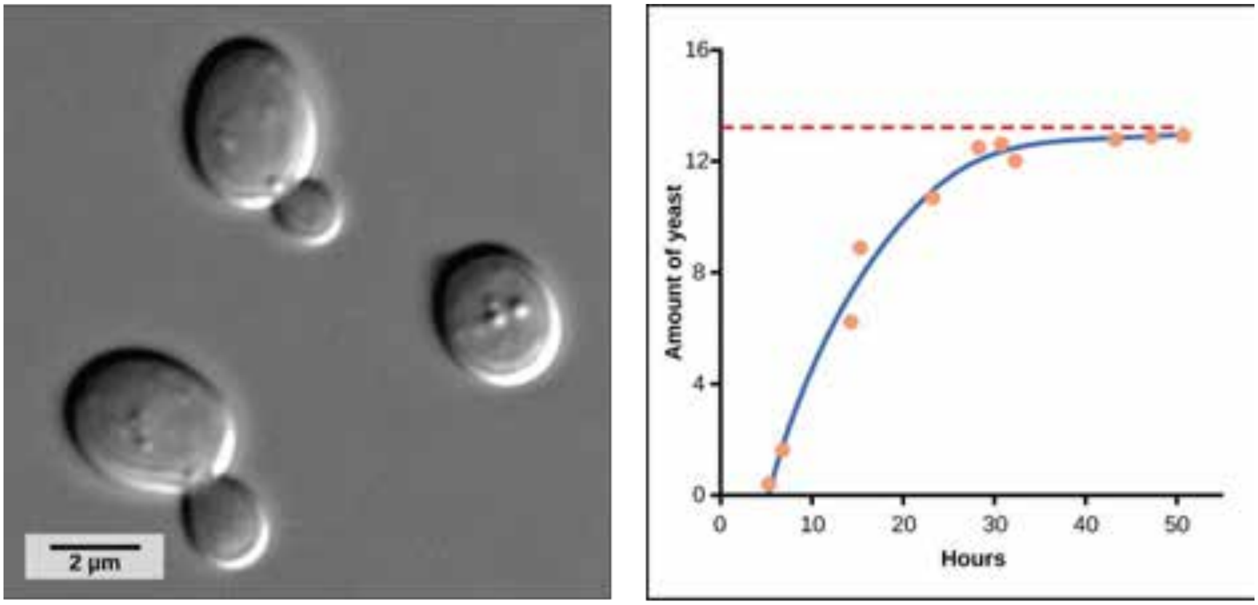
### Density-dependent Regulation

Most density-dependent factors are biological in nature and include predation, inter- and intraspecific competition, and parasites. Usually, the denser a population is, the greater its mortality rate. For example, during intra- and interspecific competition, the reproductive rates of the species will usually be lower, reducing their populations' rate of growth. In addition, low prey density increases the mortality of its predator because it has more difficulty locating its food source. Also, when the population is denser, diseases spread more rapidly among the members of the population, which affect the mortality rate.

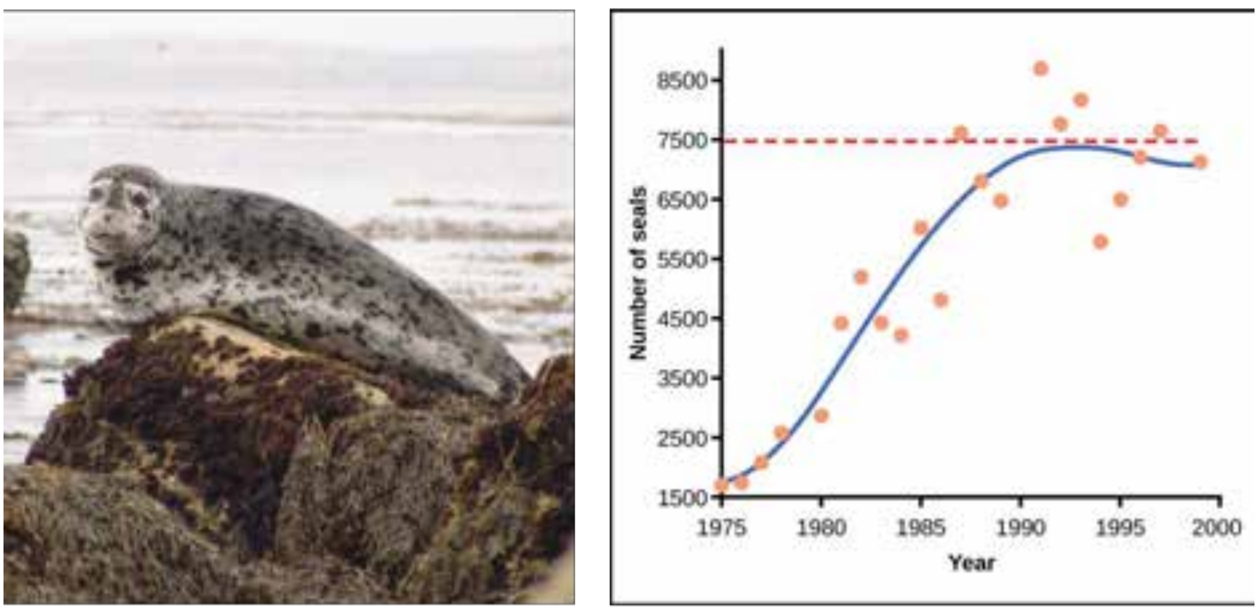
Density dependent regulation was studied in a natural experiment with wild donkey populations on two sites in Australia. On one site the population was reduced by a population control program; the population on the other site received no interference. The high-density plot was twice as dense as the low-density plot. From 1986 to 1987 the high-density plot saw no change in donkey density, while the low-density plot saw an increase in donkey density. The difference in the growth rates of the two populations was caused by mortality, not by a difference in birth rates. The researchers found that numbers of offspring birthed by each mother was unaffected by density. Growth rates in the two populations were different mostly because of juvenile mortality caused by the mother's malnutrition due to scarce high-quality food in the dense population. Figure 7.7 shows the difference in age-specific mortalities in the two populations.

### Density-independent Regulation and Interaction with Density-dependent Factors

Many factors that are typically physical in nature cause mortality of a population regardless of its density. These factors include weather, natural disasters, and pollution. An individual deer will be killed in a forest fire regardless of how many deer happen to be in that area. Its chances of survival are the same whether the population density is high or low. The same holds true for cold winter weather.




(a)




(b)

FIGURE 7.6

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

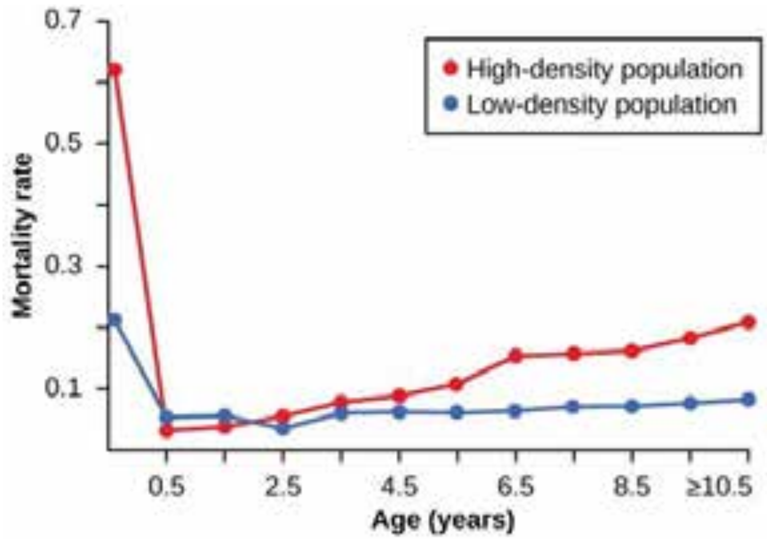



FIGURE 7.7

This graph shows the age-specific mortality rates for wild donkeys from high- and low-density populations. The juvenile mortality is much higher in the high-density population because of maternal malnutrition caused by a shortage of high-quality food.

In real-life situations, population regulation is very complicated and density-dependent and independent factors can interact. A dense population that suffers mortality from a density-independent cause will be able to recover differently than a sparse population. For example, a population of deer affected by a harsh winter will recover faster if there are more deer remaining to reproduce.

**EVOLUTION IN ACTION**

**Why Did the Woolly Mammoth Go Extinct?**

*Woolly mammoths began to go extinct about 10,000 years ago, soon after paleontologists believe humans able to hunt them began to colonize North America and northern Eurasia. A mammoth population survived on Wrangel Island, in the East Siberian Sea, and was isolated from human contact until as recently as 1700 BC. We know a lot about these animals from carcasses found frozen in the ice of Siberia and other northern regions. It is commonly thought that climate change and human hunting led to their extinction. A 2008 study estimated that climate change reduced the mammoth's range from 3,000,000 square miles 42,000 years ago to 310,000 square miles 6,000 years ago.* David Nogus–Bravo et al., "Climate Change, Humans, and the Extinction of the Woolly Mammoth." PLoS Biol 6 (April 2008) *Through archaeological evidence of kill sites, it is also well documented that humans hunted these animals. A 2012 study concluded that no single factor was exclusively responsible for the extinction of these magnificent creatures.* G.M. MacDonald et al., "Pattern of Extinction of the Woolly Mammoth in Beringia." Nature Communications 3, no. 893 (June 2012). *In addition to climate change and reduction of habitat, scientists demonstrated another important factor in the mammoth's extinction was the migration of human hunters across the Bering Strait to North America during the last ice age 20,000 years ago. The maintenance of stable populations was and is very complex, with many interacting factors determining the outcome. It is important to remember that humans are also part of nature. Once we contributed to a species' decline using primitive hunting technology only.*


FIGURE 7.8

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

**Demographic-Based Population Models**

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

## 7.3 The Human Population

Concepts of animal population dynamics can be applied to human population growth (OpenStax College, 2013). Humans are not unique in their ability to alter their environment. For example, beaver dams alter the stream environment where they are built. Humans, however, have the ability to alter their environment to increase its carrying capacity, sometimes to the detriment of other species. Earth's human population and their use of resources are growing rapidly, to the extent that some worry about the ability of Earth's environment to sustain its human population. Long-term exponential growth carries with it the potential risks of famine, disease, and large-scale death, as well as social consequences of crowding such as increased crime.

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

The world's human population is presently growing exponentially (Figure 7.9).

A consequence of exponential growth rate is that the time that it takes to add a particular number of humans to the population is becoming shorter. Figure 7.10shows that 123 years were necessary to add 1 billion humans between 1804 and 1930, but it only took 24 years to add the two billion people between 1975 and 1999. This acceleration in growth rate will likely begin to decrease in the coming decades. Despite this, the population will continue to increase and the threat of overpopulation remains, particularly because the damage caused to ecosystems and biodiversity is lowering the human carrying capacity of the planet.

### Overcoming Density-Dependent Regulation

Humans are unique in their ability to alter their environment in myriad ways. This ability is responsible for human population growth because it resets the carrying capacity and overcomes density-dependent growth regulation. Much of this ability is related to human intelligence, society, and communication. Humans construct shelters to protect themselves from the elements and have developed agriculture and domesticated animals to increase their food supplies. In addition, humans use language to communicate this technology to new generations, allowing them to improve upon previous accomplishments.

Other factors in human population growth are migration and public health. Humans originated in Africa, but we have since migrated to nearly all inhabitable land on Earth, thus, increasing the area that we have colonized. Public health, sanitation, and the use of antibiotics and vaccines have decreased the ability of infectious disease to limit human population growth in developed countries. In the past, diseases such as the bubonic plaque of the fourteenth century killed between 30 and 60 percent of Europe's population and reduced the overall world population by as many as one hundred million people. Infectious disease continues to have an impact on human population growth. For example, life expectancy in sub-Saharan Africa, which was increasing from 1950 to 1990, began to decline after 1985 largely as a result of HIV/AIDS mortality. The reduction in life expectancy caused by HIV/AIDS was estimated to be 7 years for 2005. Declining life expectancy is an indicator of higher mortality rates and leads to lower birth rates.

The fundamental cause of the acceleration of growth rate for humans in the past 200 years has been the reduced death rate due to a development of the technological advances of the industrial age, urbanization that supported those technologies, and especially the exploitation of the energy in fossil fuels. Fossil fuels are responsible for dramatically increasing the resources available for human population growth through agriculture (mechanization, pesticides, and fertilizers) and harvesting wild populations.

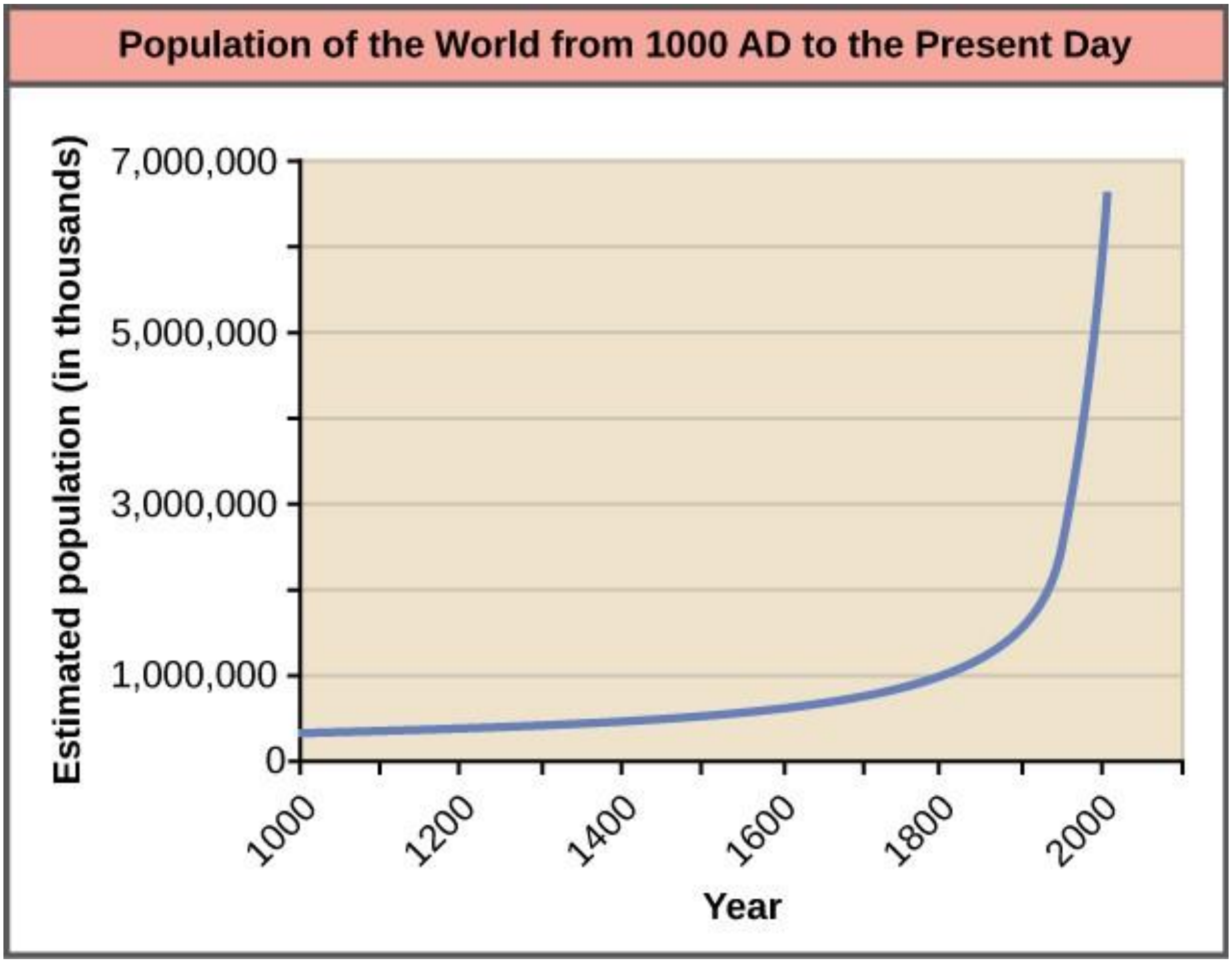



FIGURE 7.9
Human population growth since 1000 AD is exponential.

### Age Structure, Population Growth, and Economic Development

The age structure of a population is an important factor in population dynamics. **Age structure** is the proportion of a population in different age classes. Models that incorporate age structure allow better prediction of population growth, plus the ability to associate this growth with the level of economic development in a region. Countries with rapid growth have a pyramidal shape in their age structure diagrams, showing a preponderance of younger individuals, many of whom are of reproductive age (Figure 7.11). This pattern is most often observed in underdeveloped countries where individuals do not live to old age because of less-than-optimal living conditions, and there is a high birth rate. Age structures of areas with slow growth, including developed countries such as the United States, still have a pyramidal structure, but with many fewer young and reproductive-aged individuals and a greater proportion of older individuals. Other developed countries, such as Italy, have zero population growth. The age structure of these populations is more conical, with an even greater percentage of middle-aged and older individuals. The actual growth rates in different countries are shown in (Figure 7.12), with the highest rates tending to be in the less economically developed countries of Africa and Asia.

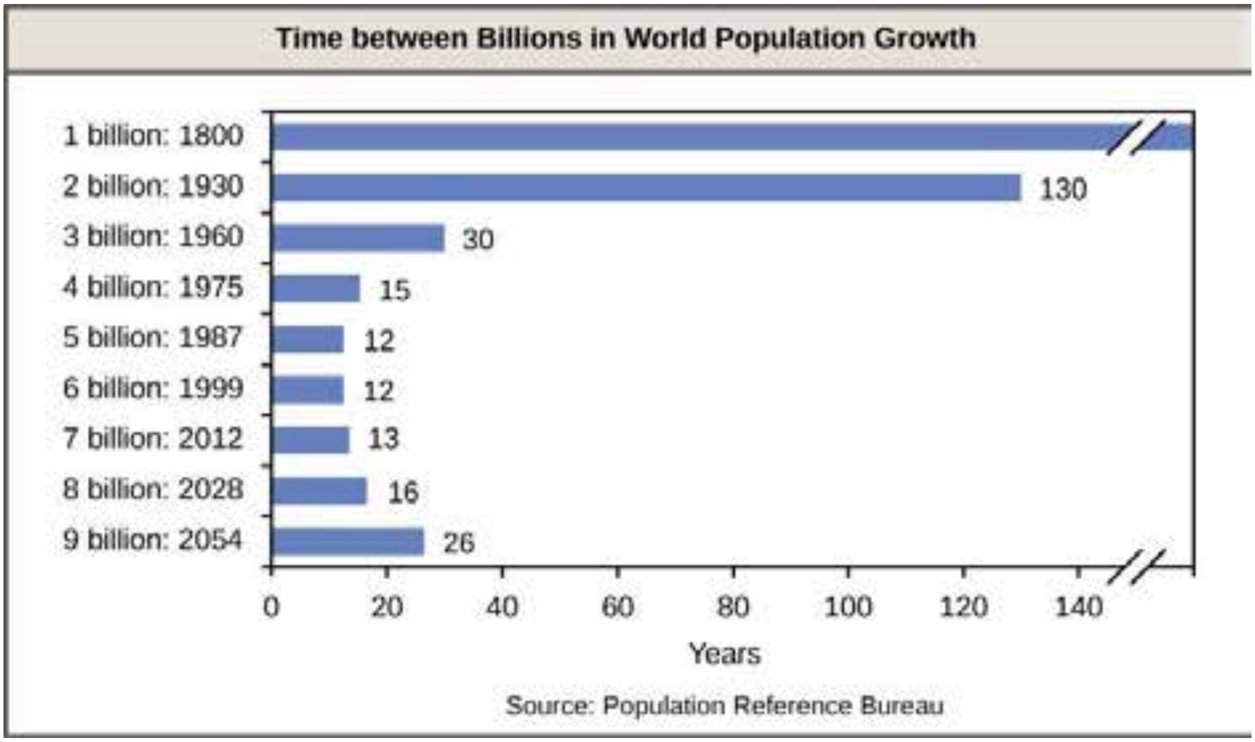



FIGURE 7.10

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

### Long-Term Consequences of Exponential Human Population Growth

Many dire predictions have been made about the world's population leading to a major crisis called the "population explosion." In the 1968 book *The Population Bomb*, biologist Dr. Paul R. Ehrlich wrote, "The battle to feed all of humanity is over. In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate. While many critics view this statement as an exaggeration, the laws of exponential population growth are still in effect, and unchecked human population growth cannot continue indefinitely.

Efforts to moderate population control led to the **one-child policy** in China, which imposes fines on urban couples who have more than one child. Due to the fact that some couples wish to have a male heir, many Chinese couples continue to have more than one child. The effectiveness of the policy in limiting overall population growth is controversial, as is the policy itself. Moreover, there are stories of female infanticide having occurred in some of the more rural areas of the country. Family planning education programs in other countries have had highly positive effects on limiting population growth rates and increasing standards of living. In spite of population control policies, the human population continues to grow. Because of the subsequent need to produce more and more food to feed our population, inequalities in access to food and other resources will continue to widen. The United Nations estimates the future world population size could vary from 6 billion (a decrease) to 16 billion people by the year 2100. There is no way to know whether human population growth will moderate to the point where the crisis described by Dr. Ehrlich will be averted.

Another consequence of population growth is the change and degradation of the natural environment. Many coun-

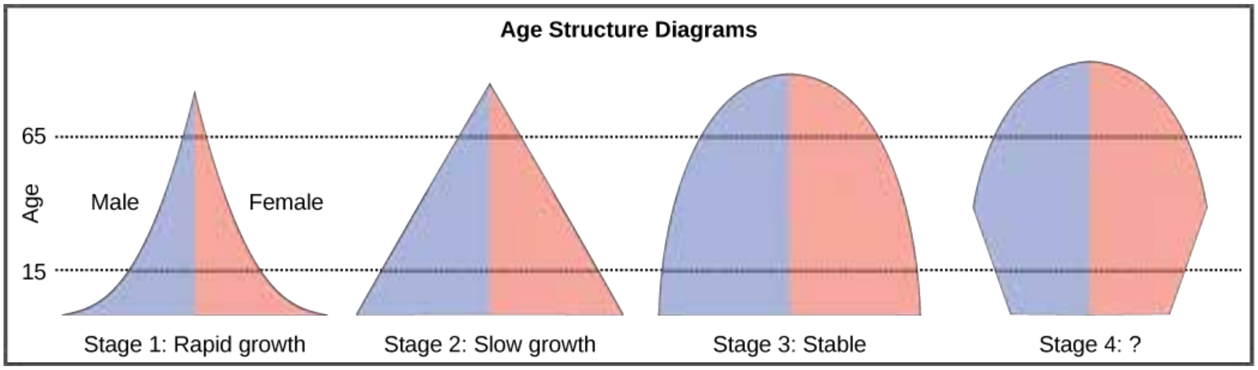



FIGURE 7.11

Typical age structure diagrams are shown. The rapid growth diagram narrows to a point, indicating that the number of individuals decreases rapidly with age. In the slow growth model, the number of individuals decreases steadily with age. Stable population diagrams are rounded on the top, showing that the number of individuals per age group decreases gradually, and then increases for the older part of the population. Age structure diagrams for rapidly growing, slow growing, and stable populations are shown in stages 1 through 3. What type of population change do you think stage 4 represents?

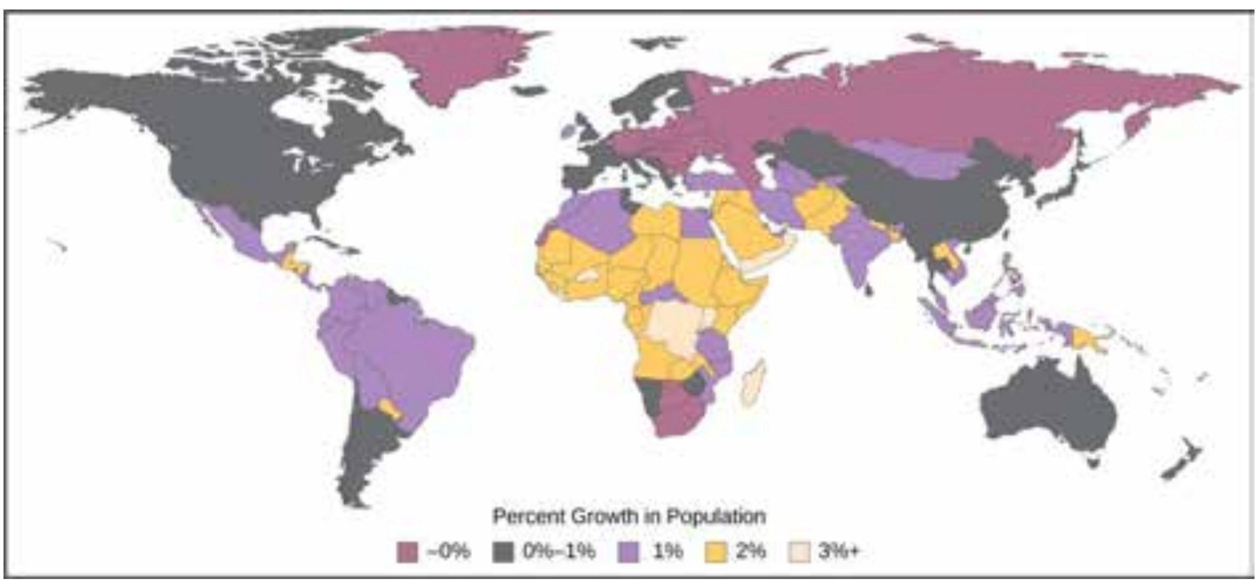



FIGURE 7.12

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

tries have attempted to reduce the human impact on climate change by limiting their emission of greenhouse gases. However, a global climate change treaty remains elusive, and many underdeveloped countries trying to improve their economic condition may be less likely to agree with such provisions without compensation if it means slowing their economic development. Furthermore, the role of human activity in causing climate change has become a hotly debated socio-political issue in some developed countries, including the United States. Thus, we enter the future with considerable uncertainty about our ability to curb human population growth and protect our environment to maintain the carrying capacity for the human species.

## 7.4 Community Ecology

In general, populations of one species never live in isolation from populations of other species (OpenStax College, 2013). The interacting populations occupying a given habitat form an ecological community. The number of species occupying the same habitat and their relative abundance is known as the diversity of the community. Areas with low species diversity, such as the glaciers of Antarctica, still contain a wide variety of living organisms, whereas the diversity of tropical rainforests is so great that it cannot be accurately assessed. Scientists study ecology at the community level to understand how species interact with each other and compete for the same resources.

### Predation and Herbivory

Perhaps the classical example of species interaction is the predator-prey relationship. The narrowest definition of the predator-prey interaction describes individuals of one population that kill and then consume the individuals of another population. Population sizes of predators and prey in a community are not constant over time, and they may vary in cycles that appear to be related. The most often cited example of predator-prey population dynamics is seen in the cycling of the lynx (predator) and the snowshoe hare (prey), using 100 years of trapping data from North America (Figure 7.13). This cycling of predator and prey population sizes has a period of approximately ten years, with the predator population lagging one to two years behind the prey population. An apparent explanation for this pattern is that as the hare numbers increase, there is more food available for the lynx, allowing the lynx population to increase as well. When the lynx population grows to a threshold level, however, they kill so many hares that hare numbers begin to decline, followed by a decline in the lynx population because of scarcity of food. When the lynx population is low, the hare population size begins to increase due, in part, to low predation pressure, starting the cycle anew.

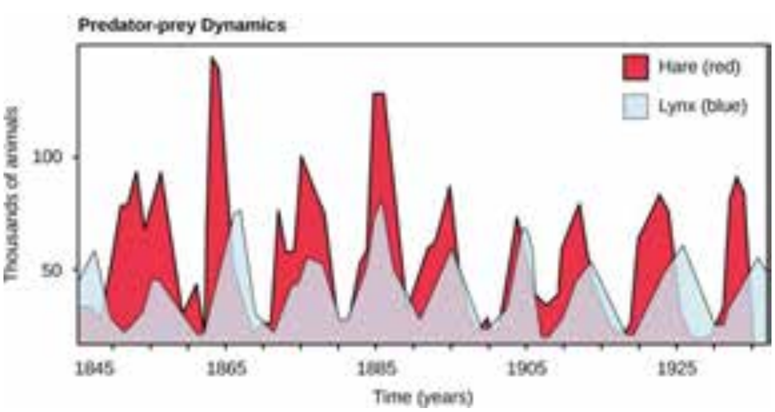



FIGURE 7.13
The cycling of snowshoe hare and lynx populations in Northern Ontario is an example of predator-prey dynamics.

### Defense Mechanisms against Predation and Herbivory

Predation and predator avoidance are strong selective agents. Any heritable character that allows an individual of a prey population to better evade its predators will be represented in greater numbers in later generations. Likewise, traits that allow a predator to more efficiently locate and capture its prey will lead to a greater number of offspring and an increase in the commonness of the trait within the population. Such ecological relationships between specific populations lead to adaptations that are driven by reciprocal evolutionary responses in those populations.

Species have evolved numerous mechanisms to escape predation and herbivory (the consumption of plants for food). Defenses may be mechanical, chemical, physical, or behavioral.

Mechanical defenses, such as the presence of armor in animals or thorns in plants, discourage predation and herbivory by discouraging physical contact (Figure 7.14). Many animals produce or obtain chemical defenses from plants and store them to prevent predation. Many plant species produce secondary plant compounds that serve no function for the plant except that they are toxic to animals and discourage consumption. For example, the foxglove produces several compounds, including digitalis, that are extremely toxic when eaten (Figure 7.14). (Biomedical scientists have purposed the chemical produced by foxglove as a heart medication, which has saved lives for many decades.)

FIGURE 7.14

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

Many species use their body shape and coloration to avoid being detected by predators. The tropical walking stick is an insect with the coloration and body shape of a twig, which makes it very hard to see when it is stationary against a background of real twigs (Figure 7.15). In another example, the chameleon can change its color to match its surroundings (Figure 7.15).

FIGURE 7.15

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

Some species use coloration as a way of warning predators that they are distasteful or poisonous. For example, the monarch butterfly caterpillar sequesters poisons from its food (plants and milkweeds) to make itself poisonous or distasteful to potential predators. The caterpillar is bright yellow and black to advertise its toxicity. The caterpillar is also able to pass the sequestered toxins on to the adult monarch, which is also dramatically colored black and red as a warning to potential predators. Fire-bellied toads produce toxins that make them distasteful to their potential predators. They have bright red or orange coloration on their bellies, which they display to a potential predator to advertise their poisonous nature and discourage an attack. These are only two examples of warning coloration, which is a relatively common adaptation. Warning coloration only works if a predator uses eyesight to locate prey and can learn—a naïve predator must experience the negative consequences of eating one before it will avoid other similarly colored individuals (Figure 7.16).

While some predators learn to avoid eating certain potential prey because of their coloration, other species have

FIGURE 7.16
(a) The tropical walking stick and (b) the chameleon use their body shape and/or coloration to prevent detection by predators. (credit a: modification of work by Linda Tanner; credit b: modification of work by Frank Vassen)

evolved mechanisms to mimic this coloration to avoid being eaten, even though they themselves may not be unpleasant to eat or contain toxic chemicals. In some cases of **mimicry**, a harmless species imitates the warning coloration of a harmful species. Assuming they share the same predators, this coloration then protects the harmless ones. Many insect species mimic the coloration of wasps, which are stinging, venomous insects, thereby discouraging predation (Figure 7.17).


FIGURE 7.17
One form of mimicry is when a harmless species mimics the coloration of a harmful species, as is seen with the (a) wasp (Polistes sp.) and the (b) hoverfly (Syrphus sp.). (credit: modification of work by Tom Ings)

In other cases of mimicry, multiple species share the same warning coloration, but all of them actually have defenses. The commonness of the signal improves the compliance of all the potential predators. Figure 7.18 shows a variety of foul-tasting butterflies with similar coloration.

### Competitive Exclusion Principle

Resources are often limited within a habitat and multiple species may compete to obtain them. Ecologists have come to understand that all species have an ecological niche. A niche is the unique set of resources used by a species, which includes its interactions with other species. The **competitive exclusion principle** states that two species cannot occupy the same niche in a habitat: in other words, different species cannot coexist in a community if they are competing for all the same resources. This principle works because if there is an overlap in resource use and therefore competition between two species, then traits that lessen reliance on the shared resource will be selected

FIGURE 7.18
Several unpleasant-tasting Heliconius butterfly species share a similar color pattern with better-tasting varieties, an example of mimicry. (credit: Joron M, Papa R, Beltrán M, Chamberlain N, Mavárez J, et al.)

for leading to evolution that reduces the overlap. If either species is unable to evolve to reduce competition, then the species that most efficiently exploits the resource will drive the other species to extinction. An experimental example of this principle is shown in Figure7.19 with two protozoan species: *Paramecium aurelia* and*Paramecium caudatum*. When grown individually in the laboratory, they both thrive. But when they are placed together in the same test tube (habitat),*P. aurelia* outcompetes *P. caudatum* for food, leading to the latter's eventual extinction.

## Symbiosis

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

### Commensalism

A commensal relationship occurs when one species benefits from a close prolonged interaction, while the other neither benefits nor is harmed. Birds nesting in trees provide an example of a commensal relationship (7.20 Figure). The tree is not harmed by the presence of the nest among its branches. The nests are light and produce little strain on the structural integrity of the branch, and most of the leaves, which the tree uses to get energy by photosynthesis, are above the nest so they are unaffected. The bird, on the other hand, benefits greatly. If the bird had to nest in the open, its eggs and young would be vulnerable to predators. Many potential commensal relationships are difficult to identify because it is difficult to prove that one partner does not derive some benefit from the presence of the other.

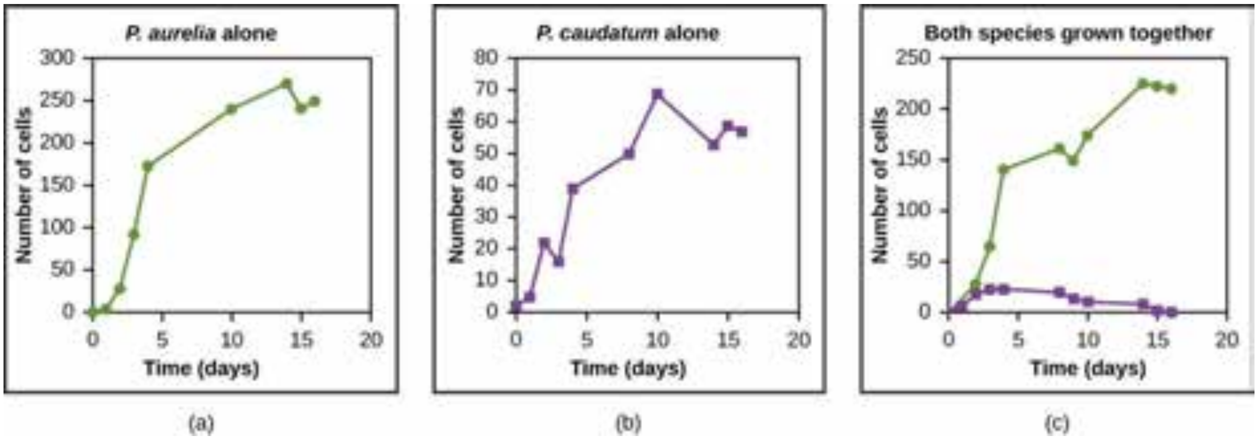



FIGURE 7.19

Paramecium aurelia and Paramecium caudatum grow well individually, but when they compete for the same resources, the P. aurelia outcompetes the P. caudatum.

FIGURE 7.20

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

### Mutualism

A second type of symbiotic relationship is called **mutualism**, in which two species benefit from their interaction. For example, termites have a mutualistic relationship with protists that live in the insect's gut (Figure 7.21). The termite benefits from the ability of the protists to digest cellulose. However, the protists are able to digest cellulose only because of the presence of symbiotic bacteria within their cells that produce the cellulase enzyme. The termite itself cannot do this: without the protozoa, it would not be able to obtain energy from its food (cellulose from the wood it chews and eats). The protozoa benefit by having a protective environment and a constant supply of food from the wood chewing actions of the termite. In turn, the protists benefit from the enzymes provided by their bacterial endosymbionts, while the bacteria benefit from a doubly protective environment and a constant source of nutrients from two hosts. Lichen are a mutualistic relationship between a fungus and photosynthetic algae or cyanobacteria. The glucose produced by the algae provides nourishment for both organisms, whereas the physical structure of the lichen protects the algae from the elements and makes certain nutrients in the atmosphere more available to the algae. The algae of lichens can live independently given the right environment, but many of the fungal partners are unable to live on their own.

FIGURE 7.21

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

#### Parasitism

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

The reproductive cycles of parasites are often very complex, sometimes requiring more than one host species. A tapeworm causes disease in humans when contaminated, undercooked meat such as pork, fish, or beef is consumed (Figure 7.22). The tapeworm can live inside the intestine of the host for several years, benefiting from the host's food, and it may grow to be over 50 feet long by adding segments. The parasite moves from one host species to a second host species in order to complete its life cycle. *Plasmodium falciparum* is another parasite: the protists that cause malaria, a significant disease in many parts of the world. Living inside human liver and red blood cells, the organism reproduces asexually in the human host and then sexually in the gut of blood-feeding mosquitoes to complete its life cycle. Thus malaria is spread from human to mosquito and back to human, one of many arthropod-borne infectious diseases of humans.

### Characteristics of Communities

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

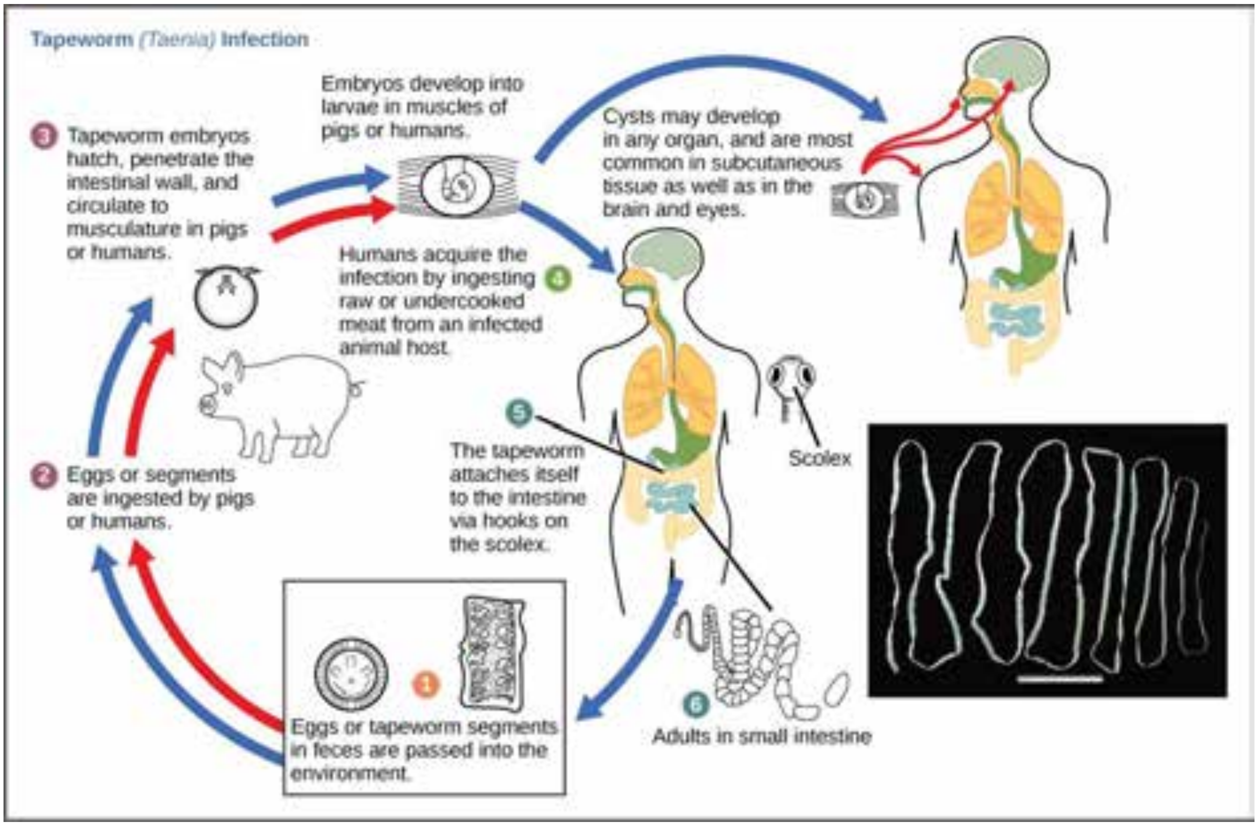



FIGURE 7.22
This diagram shows the life cycle of the tapeworm, a human worm parasite. (credit: modification of work by CDC)

### Biodiversity

Ecologists have extensively studied one of the fundamental characteristics of communities: biodiversity. One measure of biodiversity used by ecologists is the number of different species in a particular area and their relative abundance. The area in question could be a habitat, a biome, or the entire biosphere. **Species richness** is the term used to describe the number of species living in a habitat or other unit. Species richness varies across the globe (Figure 7.23). Ecologists have struggled to understand the determinants of biodiversity. Species richness is related to latitude: the greatest species richness occurs near the equator and the lowest richness occurs near the poles. Other factors influence species richness as well. **Island biogeography** attempts to explain the great species richness found in isolated islands, and has found relationships between species richness, island size, and distance from the mainland.

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

### Foundation Species

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

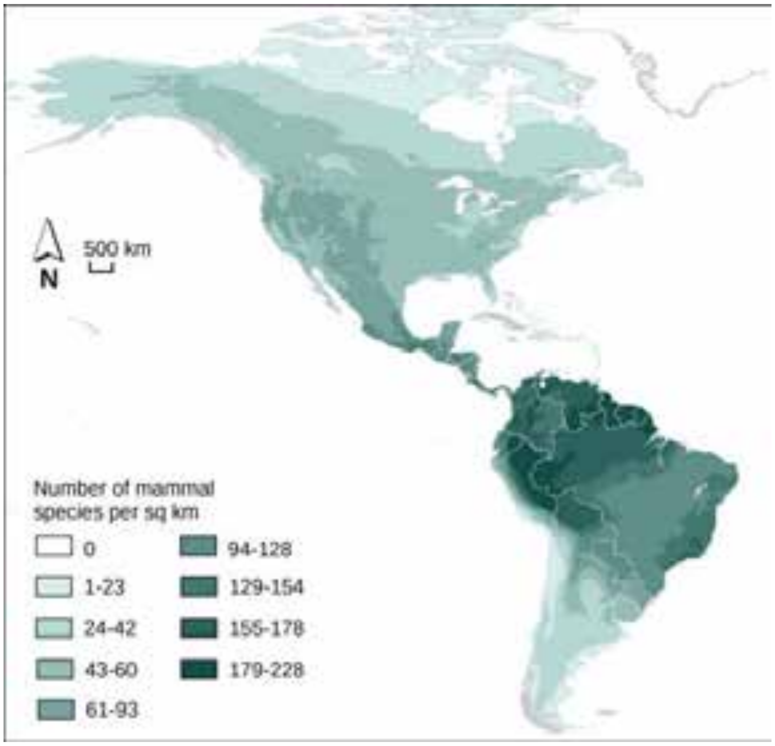



FIGURE 7.23
The greatest species richness for mammals in North America is associated in the equatorial latitudes. (credit: modification of work by NASA, CIESIN, Columbia Uni- versity)

California.

Foundation species may physically modify the environment to produce and maintain habitats that benefit the other organisms that use them. Examples include the kelp described above or tree species found in a forest. The photosynthetic corals of the coral reef also provide structure by physically modifying the environment (Figure 7.24). The exoskeletons of living and dead coral make up most of the reef structure, which protects many other species from waves and ocean currents.

FIGURE 7.24
Coral is the foundation species of coral reef ecosystems. (credit: Jim E. Maragos, USFWS)

### Keystone Species

A **keystone species** is one whose presence has inordinate influence in maintaining the prevalence of various species in an ecosystem, the ecological community's structure, and sometimes its biodiversity. *Pisaster ochraceus*, the intertidal sea star, is a keystone species in the northwestern portion of the United States (Figure 7.25). Studies have shown that when this organism is removed from communities, mussel populations (their natural prey) increase, which completely alters the species composition and reduces biodiversity. Another keystone species is the banded tetra, a fish in tropical streams, which supplies nearly all of the phosphorus, a necessary inorganic nutrient, to the rest of the community. The banded tetra feeds largely on insects from the terrestrial ecosystem and then excretes phosphorus into the aquatic ecosystem. The relationships between populations in the community, and possibly the biodiversity, would change dramatically if these fish were to become extinct.

FIGURE 7.25

The Pisaster ochraceus sea star is a keystone species. (credit: Jerry Kirkhart)

### BIOLOGY IN ACTION

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

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

Voracious feeders and rapid reproducers, Asian carp may outcompete native species for food and could lead to their extinction. One species, the grass carp, feeds on phytoplankton and aquatic plants. It competes with native species for these resources and alters nursery habitats for other fish by removing aquatic plants. Another species, the silver carp, competes with native fish that feed on zooplankton. In some parts of the Illinois River, Asian carp constitute 95 percent of the community's biomass. Although edible, the fish is bony and not desired in the United States. Moreover, their presence now threatens the native fish and fisheries of the Great Lakes, which are important to local economies and recreational anglers. Asian carp have even injured humans. The fish, frightened by the sound of approaching motorboats, thrust themselves into the air, often landing in the boat or directly hitting boaters.

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

The issues associated with Asian carp show how population and community ecology, fisheries management, and politics intersect on issues of vital importance to the human food supply and economy. Socio-political issues like the Asian carp make extensive use of the sciences of population ecology, the study of members of a particular species occupying a habitat; and community ecology, the study of the interaction of all species within a habitat.

## Community Dynamics

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

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

### Primary Succession and Pioneer Species

Primary succession occurs when new land is formed, for example, following the eruption of volcanoes, such as those on the Big Island of Hawaii. As lava flows into the ocean, new land is continually being formed. On the Big Island, approximately 32 acres of land is added to it its size each year. Weathering and other natural forces break down the rock enough for the establishment of hearty species such as lichens and some plants, known as **pioneer species** (Figure 7.26). These species help to further break down the mineral-rich lava into soil where other, less hardy but more competitive species, such as grasses, shrubs, and trees, will grow and eventually replace the pioneer species. Over time the area will reach an equilibrium state, with a set of organisms quite different from the pioneer species.

FIGURE 7.26
During primary succession in lava on Maui, Hawaii, succulent plants are the pioneer species. (credit: Forest and Kim Starr)

### Secondary Succession

A classic example of secondary succession occurs in oak and hickory forests cleared by wildfire (Figure 7.27). Wildfires will burn most vegetation, and unless the animals can flee the area, they are killed. Their nutrients, however, are returned to the ground in the form of ash. Thus, although the community has been dramatically altered, there is a soil ecosystem present that provides a foundation for rapid recolonization.

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

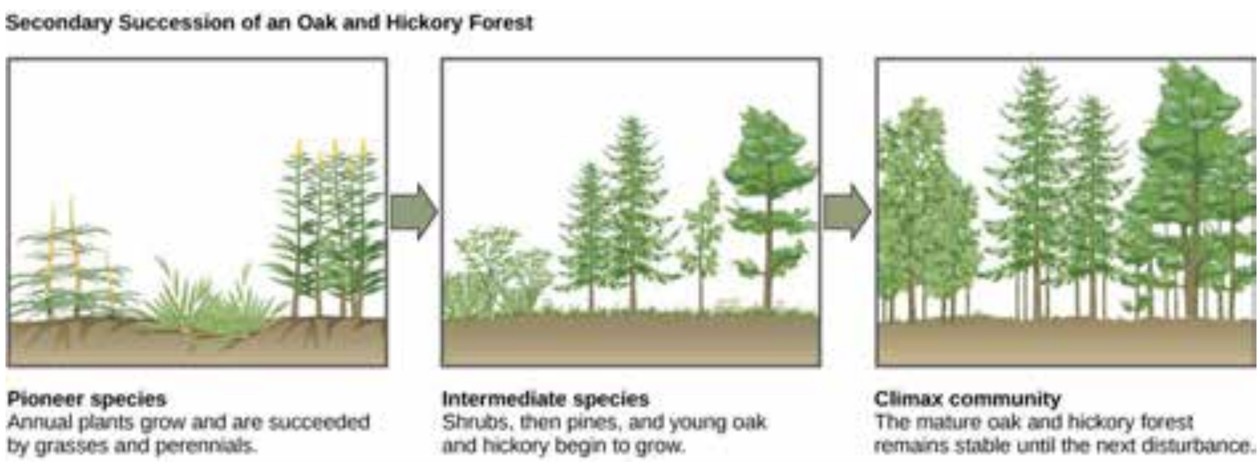



FIGURE 7.27
Secondary succession is seen in an oak and hickory forest after a forest fire. A sequence of the community present at three successive times at the same location is depicted.

# 7.5 Resources

## Summary

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

## Review Questions

1. Describe how a researcher would determine the size of a penguin population in Antarctica using the mark and release method.
2. Describe the growth at various parts of the S-shaped curve of logistic growth.
3. Give an example of how density-dependent and density-independent factors might interact.
4. Describe the age structures in rapidly growing countries, slowly growing countries, and countries with zero population growth.
5. Describe the competitive exclusion principle and its effects on competing species.

## 7.6 References

OpenStax College. (2013). *Concepts of biology*. Retrieved from http://cnx.org/contents/b3c1e1d2-839c-42b0-a314- e119a8aafbdd@8.10. OpenStax CNX. Available under Creative Commons Attribution License 3.0 (CC BY 3.0). Modified from original.

# CHAPTER 8 Environmental Hazards and Human Health

## Chapter Outline



FIGURE 8.1

Bayee Waqo (12) was named after her grandmother Bayee Chumee (82). When her son and his wife both died of AIDS, Chumee took on the care of their daughter who was just two years old. Some years later, after repeated illness, the young girl was diagnosed HIV positive, and she has been on treatment since. At 82, Chumee is getting too weak for all the household chores, so her granddaughter helps by collecting firewood, fetching water, making coffee and baking bread.

Legesse, T. (2013). Bayee Chumee and Bayee Waqo. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/Category:AIDS_in_Africa#/media/File:12._Bayee_Chumee_and_Bayee_Waqo_(10995486103).jpg

## Learning Outcomes

After studying this chapter, you should be able to:

- Define environmental health
- Categorize environmental health risks
- Explain the concept of emerging diseases
- Summarize the principles of environmental toxicology
- Classify environmental contaminants

# 8.1 The Impacts of Environmental Conditions

When environmental conditions are degraded such that the range of tolerance is exceeded, there will be a significant impact on human health. Our industrialized society dumps huge amounts of pollutants and toxic wastes into the earth's biosphere without fully considering the consequences. Such actions seriously degrade the health of the earth's ecosystems, and this degradation ultimately affects the health and well-being of human populations (University of California College Prep, 2012).

For most of human history, **biological agents** were the most significant factor in health. These included pathogenic (disease causing) organisms such as bacteria, viruses, protozoa, and internal parasites. In modern times, cardiovascular diseases, cancer, and accidents are the leading killers in most parts of the world. However, infectious diseases still cause about 22 million deaths a year, mostly in undeveloped countries. These diseases include: tuberculosis, malaria, pneumonia, influenza, whooping cough, dysentery and Acquired Immune Deficiency Syndrome (AIDS). Most of those affected are children. Malnutrition, unclean water, poor sanitary conditions and lack of proper medical care all play roles in these deaths. Compounding the problems of infectious diseases are factors such as drug-resistant pathogens, insecticide resistant carriers and overpopulation. Overuse of antibiotics have allowed pathogens to develop a resistance to drugs. For example, tuberculosis (TB) was nearly eliminated in most parts of the world, but drug-resistant strains have now reversed that trend. Another example is malaria. The insecticide DDT (Dichlorodiphenyltrichloroethane) was widely used to control malaria-carrying mosquito populations in tropical regions. However, after many years the mosquitoes developed a natural resistance to DDT and again spread the disease widely. Anti-malarial medicines were also over-prescribed, which allowed the malaria pathogen to become drug-resistant.

### ENVIRONMENTAL PERSISTENCE OF DDT

The pesticide DDT was widely used for decades. It was seen as an ideal pesticide because it is inexpensive and breaks down slowly in the environment. Unfortunately, the latter characteristic allows it to biomagnify through the food chain. Populations of bird species at the top of the food chain, e.g., eagles and pelicans, are greatly affected by DDT in the environment. When these birds have sufficient levels of DDT, the shells of their eggs are so thin that they break, making reproduction impossible. After DDT was banned in the United States in 1972, affected bird populations made noticeable recoveries.

In our industrialized society, **chemical agents** also have significant effects on human health. Toxic heavy metals, dioxins, pesticides, and endocrine disrupters are examples of these chemical agents. Heavy metals (mercury, lead, cadmium, bismuth, selenium, chromium, thallium) are typically produced as by-products of mining and manufacturing processes. All of them biomagnify (become more concentrated in species with increasing food chain level). Mercury from polluted water can accumulate in swordfish to levels toxic to humans. When toxic heavy metals get into the body, they accumulate in tissues and may eventually cause sickness or death. Studies show that people with above-average lead levels in their bones have an increased risk of developing attention deficit disorder and aggressive behavior. Lead can also damage brain cells and affect muscular coordination.

# 8.2 Environmental Health

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

| Underlying Determinants | Possible Adverse Health and Safety Consequences |
|---|---|
| Inadequate water (quantity and quality), sanitation (wastewater and excreta removal) and solid waste disposal, improper hygiene (hand washing) | Diarrheas and vector-related diseases, eg, malaria, schistosomiasis, dengue |
| Improper water resource management (urban and rural), including poor drainage | Vector-related diseases, eg, malaria, schistosomiasis |
| Crowded housing and poor ventilation of smoke | Acute and chronic respiratory diseases, including lung cancer (from coal and tobacco smoke inhalation) |
| Exposures to vehicular and industrial air pollution | Respiratory diseases, some cancers, and loss of IQ in children |
| Population movement and encroachment and construction, which affect feeding and breeding grounds of vectors, such as mosquitoes | Vector-related diseases, eg, malaria, schistosomiasis, and dengue fever, may also help spread other infectious diseases eg HIV/AIDS, Ebola fever |
| Exposure to naturally occurring toxic substances | Poisoning from, eg, arsenic, manganese, and fluorides |
| Natural resource degradation, eg, mudslides, poor drainage, erosion | Injury and death from mudslides and flooding |
| Climate change, partly from combustion of greenhouse gases in transportation, industry and poor energy conservation in housing, fuel, commerce, industry | Injury/death from: extreme heat/cold, storms, floods, fires. Indirect effects: spread of vector-borne diseases, aggravation of respiratory diseases, population dislocation, water pollution from sea level rise, etc. |
| Ozone depletion from industrial and commercial activity | Skin cancer, cataracts. Indirect effects: compromised food production, etc. |

FIGURE 8.2

Typical Environmental Health Issues: Determinants and Health Consequences.

World Bank. (2017). Environmental health. Washington, DC: World Bank. © World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/9734/536580BRI0ENGL10Box345621B01PUBLIC1.pdf?sequence=1&isAllowed=y.

### Poverty, Health and Environment

Environmental health risks can be grouped into two broad categories (World Bank, 2017). **Traditional hazards** related to poverty and lack of development affect developing countries and poor people most. Their impact exceeds that of modern health hazards by a factor of 10 in Africa, 5 in Asian countries (except for China), and 2.5 in Latin America and Middle East (see Figure 8.3). *Water-related diseases* caused by inadequate water supply and sanitation impose an especially large health burden in Africa, Asia, and the Pacific region. In India alone, over 700,000 children under 5 die annually from *diarrhea*. In Africa, *malaria* causes about 800,000 deaths annually. More than half of the world's households use unprocessed *solid fuels*, particularly biomass (crop residues, wood, and dung) for cooking and heating in inefficient stoves without proper ventilation, exposing people—mainly poor women and children—to high levels of *indoor air pollution* (IAP). IAP causes about 2 million deaths in each year.

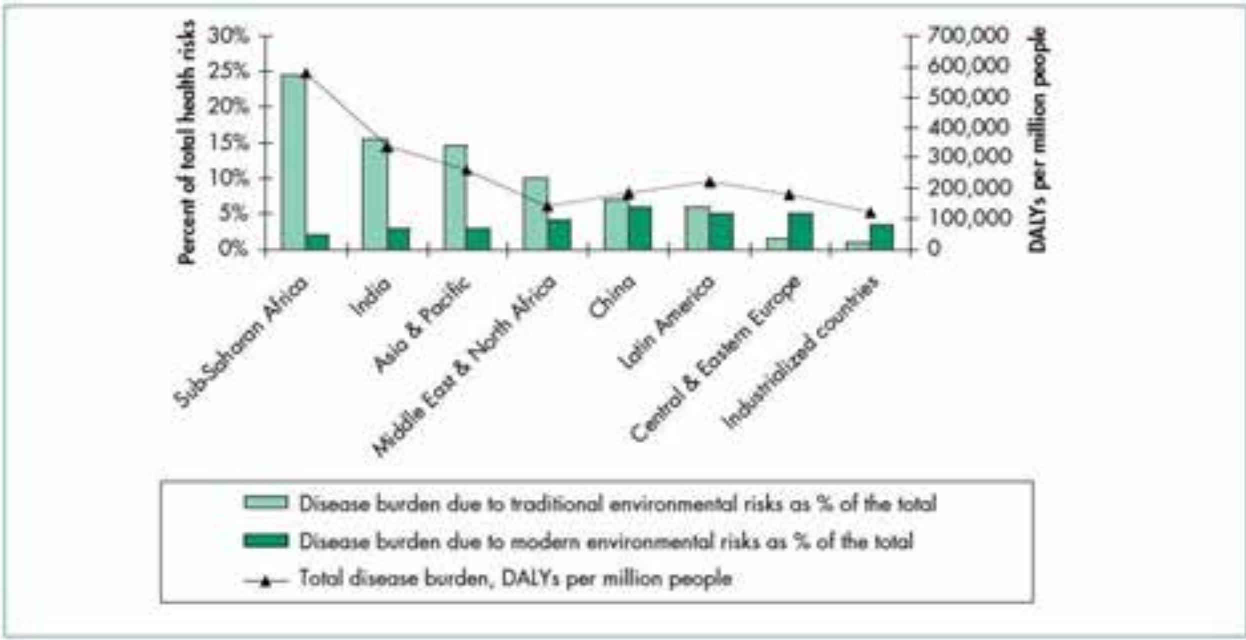



FIGURE 8.3

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

World Bank. (2017). Environmental health. Washington, DC : World Bank. © World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/9734/536580BRI0ENGL10Box345621B01PUBLIC1.pdf?sequence=1&isAllowed=y

**Modern hazards**, caused by development that lacks environmental safeguards, such as urban (outdoor) air pollution and exposure to agro-industrial chemicals and waste, prevail in industrialized countries, where exposure to traditional hazards is low (World Bank, 2017). But the contribution of modern environmental risks to the disease burden in most developing countries is similar to – and in quite a few countries, greater than – that in rich countries. *Urban air pollution*, for example, is highest in parts of China, India and some cities in Asia and Latin America. Poor people increasingly experience a "**double burden**" of traditional and modern environmental health risks. Their total burden of illness and death from all causes per million people is about twice that in rich countries, and the disease burden from environmental risks is 10 times greater.

## Environmental Health and Child Survival

The top killers of children under five are acute respiratory infections (from indoor air pollution); diarrheal diseases (mostly from poor water, sanitation, and hygiene); and malaria (from inadequate environmental management and vector control) (World Bank, 2008, 2009). Children are especially susceptible to environmental factors that put them at risk of developing illness early in life. **Malnutrition** (the condition that occurs when body does not get enough nutrients) is an important contributor to child mortality—malnutrition and environmental infections are inextricably linked.

The World Health Organization (WHO) recently concluded that about 50 percent of the consequences of malnutrition are in fact caused by inadequate water and sanitation provision and poor hygienic practices.

FIGURE 8.4

Malnourished children in Niger, during the 2005 famine.
Bavier, J. (2001). Malnourished children in Niger, during the 2005 famine. [JPG]. Retrieved from https://en.wikipedia.org/wiki/2005%E2%80%9306_Niger_food_crisis#/media/File:Niger_childhood_malnutrition_16oct06.jpg

**Poor Water and Sanitation Access**

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

**Indoor Air Pollution** (Major concerns in developing countries)

Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7 percent of global burden of disease (World Bank, 2008, 2009). It is estimated that half of the world's population, mainly in developing countries, uses solid fuels (biomass and coal) for household cooking and space heating. Cooking and heating with such solid fuels on open fires or stoves without chimneys lead to indoor air pollution, which, in turn, results in respiratory infections. Exposure to these health-damaging pollutants is particularly high among women and children in developing countries, who spend the most time inside the household. As many as half of the deaths attributable to indoor use of solid fuel are of children under the age of five.

**Malaria**

Approximately 40% of the world's people—mostly those living in the world's poorest countries—are at risk from malaria. Every year, more than 500 million people become severely ill with malaria, with most cases and deaths found in Sub-Saharan Africa. However, Asia, Latin America, the Middle East, and parts of Europe are also affected. Pregnant women are especially at high risk of malaria. Non-immune pregnant women risk both acute and severe clinical disease, resulting in fetal loss in up to 60 percent of such women and maternal deaths in more than 10 percent, including a 50 percent mortality rate for those with severe disease. Semi-immune pregnant women with malaria infection risk severe anemia and impaired fetal growth, even if they show no signs of acute clinical disease. An estimated 10,000 women and 200,000 infants die annually as a result of malaria infection during pregnancy.

## Emerging Diseases

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

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

**Ebola**, previously known as Ebola hemorrhagic fever, is a rare and deadly disease caused by infection with one of the Ebola virus strains. Ebola can cause disease in humans and nonhuman primates (CDC, 2019). The 2014 Ebola epidemic is the largest in history (with over 28,000 cases and 11,302 deaths), affecting multiple countries in West Africa. There were a small number of cases reported in Nigeria and Mali and a single case reported in Senegal; however, these cases were contained, with no further spread in these countries.

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

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

## Antibiotic Resistance

Antibiotics and similar drugs, together called antimicrobial agents, have been used for the last 70 years to treat patients who have infectious diseases. Since the 1940s, these drugs have greatly reduced illness and death from infectious diseases. However, these drugs have been used so widely and for so long that the infectious organisms the antibiotics are designed to kill have adapted to them, making the drugs less effective. Antibiotic resistance occurs when bacteria change in a way that reduces the effectiveness of drugs, chemicals, or other agents designed to cure or prevent infections. The bacteria survive and continue to multiply, causing more harm (Figure 8.5).

New forms of antibiotic resistance can cross international boundaries and spread between continents with ease. Many forms of resistance spread with remarkable speed. Each year in the United States, at least 2 million people acquire serious infections with bacteria that are resistant to one or more of the antibiotics designed to treat those infections. At least 23,000 people die each year as a direct result of these antibiotic-resistant infections. Many more die from other conditions that were complicated by an antibiotic- resistant infection. The use of antibiotics is the single most important factor leading to antibiotic resistance around the world. Antibiotics are among the **most commonly prescribed drugs** used in human medicine, but up to 50% of all the antibiotics prescribed for people are not needed or are not optimally effective as prescribed (CDC, 2013).

During recent years, there has been growing concern over Methicillin-resistant *Staphylococcus aureus* (**MRSA**), a bacteria that is resistant to many antibiotics. In the community, most MRSA infections are skin infections. In medical facilities, MRSA causes life-threatening bloodstream infections, pneumonia and surgical site infections (CDC, 2015).


FIGURE 8.5

CDC. (2013). Antibiotic resistance threats in the United States, 2013. Retrieved from https://www.cdc.gov/drugresistance/pdf/ar-threats-2013-508.pdf. Modified from original.

## 8.3 Environmental Toxicology

Environmental toxicology is the scientific study of the health effects associated with exposure to **toxic chemicals** and systems occurring in the natural, work, and living environments; the management of environmental toxins and toxicity; and the development of protections for humans, animals, and plants (Table 8.1).

TABLE 8.1: The ATSDR 2013 Substance Priority List. The table below lists top 20 substances, in order of priority, which are determined to pose the most significant potential threat to human health. This priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at various sites.

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

#### Routes of Exposure to Chemicals

In order to cause health problems, chemicals must enter your body. There are three main "routes of exposure," or ways a chemical can get into your body (OSHA, 2013).

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

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

## What Forms do Chemicals Take?

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

Detecting some forms of chemicals can be difficult. Solids and liquids are easier to recognize since they can be seen. Dusts and mists may or may not be visible, depending upon their size and concentration. Fumes, vapors, and gases are usually invisible.

## What Health Effects Can Chemicals Cause?

An **acute effect** of a contaminant (The term "contaminant" means hazardous substances, pollutants, pollution, and chemicals) is one that occurs rapidly after exposure to a large amount of that substance (OSHA, 2013). A chronic effect of a contaminant results from exposure to small amounts of a substance over a long period of time. In such a case, the effect may not be immediately obvious. **Chronic effect** are difficult to measure, as the effects may not be seen for years. Long-term exposure to cigarette smoking, low level radiation exposure, and moderate alcohol use are all thought to produce chronic effects.

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

Much of the dose-response information also comes from animal testing. Mice, rats, monkeys, hamsters, pigeons, and guinea pigs are commonly used for dose-response testing. A population of laboratory animals is exposed to measured doses under controlled conditions and the effects noted and analyzed. Animal testing poses numerous problems, however. For instance, the tests may be painful to animals, and unrelated species can react differently to the same toxin. In addition, the many differences between test animals and humans makes extrapolating test results to humans very difficult. A dose that is lethal to 50 percent of a population of test animals is called the **lethal dose-50 percent** or **LD-50**. Determination of the LD-50 is required for new synthetic chemicals in order to give a measure of their toxicity. A dose that causes 50 percent of a population to exhibit any significant response (e.g., hair loss, stunted development) is referred to as the effective dose-50 percent or ED-50. Some toxins have a threshold amount below which there is no apparent effect on the exposed population.

Some scientists believe that all toxins should be kept at a zero-level threshold because their effects at low levels are not well known. That is because of the synergy effect in which one substance exacerbates the effects of another. For example, if cigarette smoking increases lung cancer rates 20 times and occupational asbestos exposure also increases lung cancer rates 20 times, then smoking and working in an asbestos plant may increase lung cancer rates up to 400 times.

### Environmental Contaminants

The contamination of the air, water, or soil with potentially harmful substances can affect any person or community. Contaminants (Table 8.2) are often chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources. Sometimes harmful environmental contaminants occur biologically, such as mold or a toxic algae bloom.

TABLE 8.2: Classification of Environmental Contaminants

| Contaminant | Definition |
|---|---|
| **Carcinogen** | An agent which may produce cancer (uncontrolled cell growth), either by itself or in conjunction with another substance. Examples include formaldehyde, asbestos, radon, vinyl chloride, and tobacco. |
| **Suspect Carcinogen** | An agent which is suspected of being a carcinogen based on chemical structure, animal research studies, or mutagenicity studies. |
| **Confirmed Animal Carcinogen with Unknown Relevance to Humans** | An agent that is carcinogenic in experimental animals at a relatively high dose, by routes of administration, at sites, or histologic types, or by mechanisms that may not be relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure. |
| **Teratogen** | A substance which can cause physical defects in a developing embryo. Examples include alcohol and cigarette smoke. |
| **Mutagen** | A material that induces genetic changes (mutations) in the DNA. Examples include radioactive substances, x-rays and ultraviolet radiation. |
| **Neurotoxicant** | A substance that can cause an adverse effect on the chemistry, structure or function of the nervous system. Examples include lead and mercury. |
| **Endocrine disruptor** | A chemical that may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife. A wide range of substances, both natural and man-made, are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, arsenic, polychlorinated biphenyls (PCBs), DDT and other pesticides, and plasticizers such as bisphenol A (BPA). Endocrine disruptors may be found in many everyday products– including plastic bottles, metal food cans, detergents, flame retardants, food, toys, cosmetics, and pesticides. Research shows that endocrine disruptors may pose the greatest risk during prenatal and early postnatal development when organ and neural systems are forming. |

The following are some environmental contaminants that can affect a community or an individual's health (Tox Town, 2018).

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

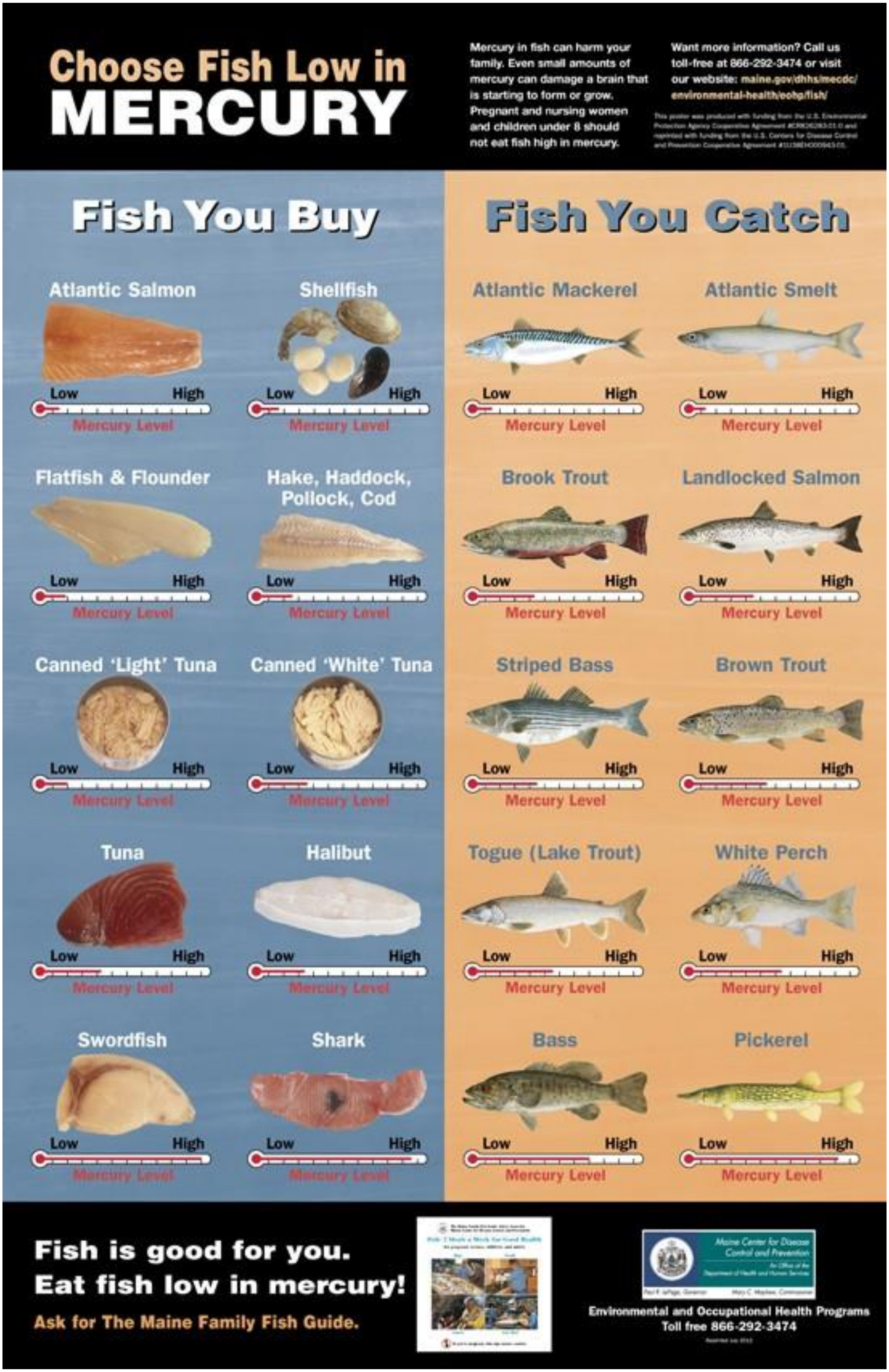
Most arsenic gets into the body through ingestion of food or water. Arsenic in drinking water is a problem in many countries around the world, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the United States. Arsenic may also be found in foods, including rice and some fish, where it is present due to uptake from soil and water. It can also enter the body by breathing dust containing arsenic, or through the skin, though this is not a major route of exposure. Researchers are finding that arsenic, even at low levels, can interfere with the body's endocrine system. In several cell culture and animal models, arsenic has been found to act as an endocrine disruptor, which may underlie many of its health effects. Arsenic is also a known human carcinogen associated with skin, lung, bladder, kidney, and liver cancer.

**Polychlorinated biphenyls**, commonly called PCBs, are mixtures of up to 209 chlorinated compounds that do not occur naturally. They have no taste or smell. PCBs are persistent organic pollutants (POPs) and endocrine disruptors. 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. But, before 1977, PCBs were used as insulation, as plasticizers, and in surface coatings, sealants, fire retardants, glues, inks, pesticides, and carbonless copy paper. PCBs don't break down easily in the environment and may remain there for very long periods of time. Studies indicate that PCBs are associated with certain kinds of cancer in humans. Women who were exposed to relatively high levels of PCBs in the workplace or ate large amounts of fish contaminated with PCBs had babies that weighed slightly less than babies from women who did not have these exposures.

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

Although fish and shellfish have many nutritional benefits, consuming large quantities of fish increases a person's exposure to mercury. Pregnant women who eat fish high in mercury on a regular basis run the risk of permanently damaging their developing fetuses. Children born to these mothers may exhibit motor difficulties, sensory problems and cognitive deficits. The poster 8.6 (published by the Maine Center for Disease Control & Prevention) identifies the typical (average) amounts of mercury in commonly consumed commercial and sport-caught fish.

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



Choose Fish Low in
MERCURY
Mercury in fish can harm your family. Even small amounts of mercury can damage a brain that is starting to form or grow. Pregnant and nursing women and children under 8 should not eat fish high in mercury.
Want more information? Call us toll-free at 866-292-3474 or visit our website: maine.gov/dhhs/mecdc/environmental-health/eohp/fish/
Fish You Buy
Atlantic Salmon
Low
High
Mercury Level
Shellfish
Low
High
Mercury Level
Flatfish & Flounder
Low
High
Mercury Level
Hake, Haddock, Pollock, Cod
Low
High
Mercury Level
Canned 'Light' Tuna
Low
High
Mercury Level
Canned 'White' Tuna
Low
High
Mercury Level
Tuna
Low
High
Mercury Level
Halibut
Low
High
Mercury Level
Swordfish
Low
High
Mercury Level
Shark
Low
High
Mercury Level
Fish You Catch
Atlantic Mackerel
Low
High
Mercury Level
Atlantic Smelt
Low
High
Mercury Level
Brook Trout
Low
High
Mercury Level
Landlocked Salmon
Low
High
Mercury Level
Striped Bass
Low
High
Mercury Level
Brown Trout
Low
High
Mercury Level
Togue (Lake Trout)
Low
High
Mercury Level
White Perch
Low
High
Mercury Level
Bass
Low
High
Mercury Level
Pickerel
Low
High
Mercury Level
Fish is good for you.
Eat fish low in mercury!
Ask for The Maine Family Fish Guide.
Maine Center for Disease Control and Prevention
Environmental and Occupational Health Programs
Toll free 866-292-3474

**BOX 1. What can I do to prevent exposure toBPA?**

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

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

**Dioxins** are a class of chemical contaminants that are formed during combustion processes such as waste incineration, forest fires, and backyard trash burning, as well as during some industrial processes such as paper pulp bleaching and herbicide manufacturing (Tox Town, 2018). The highest environmental concentrations of dioxin are usually found in soil and sediment, with much lower levels found in air and water. We are primarily exposed to dioxins by eating food contaminated by these chemicals. Studies have also shown that chemical workers who are exposed to high levels of dioxins have an increased risk of cancer. Other studies of show that dioxins can cause reproductive and developmental problems, and an increased risk of heart disease and diabetes.

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

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

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

**Polyvinyl chloride (PVC)** is an odorless and solid plastic. It is most commonly white but can also be colorless or amber. It can also come in the form of white powder or pellets. PVC is made from vinyl chloride. PVC is made softer and more flexible by the addition of phthalates. Bisphenol A (BPA) is also used to make PVC plastics. PVC contains high levels of chlorine. PVC is used to make pipes, pipe fittings, pipe conduits, vinyl flooring, and vinyl siding. When softened with phthalates, PVC is used to make some medical devices (including intravenous (IV) bags, blood bags, blood and respiratory tubing) and consumer products (raincoats, toys, shower curtains, furniture, carpet backing, plastic bags and credit cards). Most vinyl chloride produced in the United States is used to make PVC.

Exposure to PVC often includes exposure to phthalates, which are used to soften PVC and may have adverse health effects. Because of PVC's heavy chlorine content, dioxins are released during the manufacturing, burning, or landfilling of PVC. Exposure to dioxins can cause reproductive, developmental, and other health problems, and at least one dioxin is classified as a carcinogen. Dioxins, phthalates, and BPA are suspected to be endocrine disruptors, which are chemicals that may interfere with the production or activity of hormones in the human endocrine system.

**Formaldehyde** is a colorless, flammable gas or liquid that has a pungent, suffocating odor (Tox Town, 2018). It is a volatile organic compound, which is an organic compound that easily becomes a vapor or gas. It is also naturally produced in small, harmless amounts in the human body. The primary way we can be exposed to formaldehyde is by breathing air containing it. Releases of formaldehyde into the air occur from industries using or manufacturing formaldehyde, wood products (such as particle-board, plywood, and furniture), automobile exhaust, cigarette smoke, paints and varnishes, and carpets and permanent press fabrics. Nail polish, and commercially applied floor finish emit formaldehyde.

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

## Radiation

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

**Radon** is a colorless, odorless radioactive gas (Tox Town, 2018). It comes from the natural decay of uranium or thorium found in nearly all soils. It typically moves up through the ground and into the home through cracks in floors, walls and foundations. It can also be released from building materials or from well water. Radon breaks down quickly, giving off radioactive particles. Long-term exposure to these particles can lead to lung cancer. Radon is the leading cause of lung cancer among nonsmokers, according to the U.S. Environmental Protection Agency, and the second leading cause behind smoking.

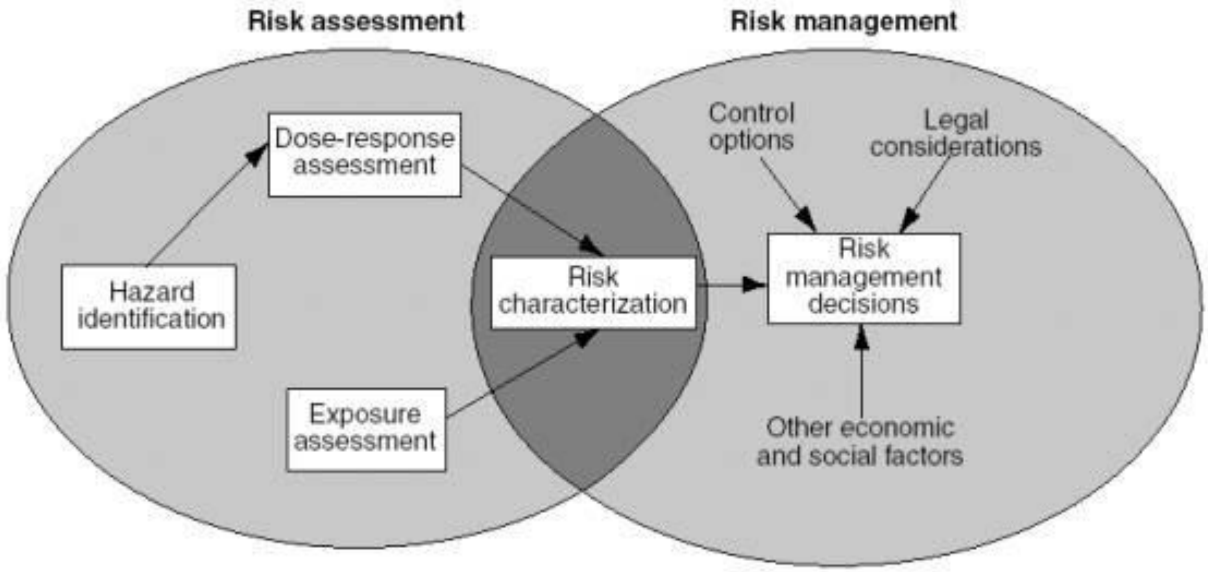
## 8.4 Risk Assessment and Management

**Risk assessment** is a scientific process used by federal agencies and risk management decision-makers to make informed decisions about actions that may be taken to protect human health by ascertaining potential human health risks or health hazard associated with exposure to chemicals in the environment (EPA, 2013). Some of the real-world examples of risk assessment includes: establishment of national ambient air quality and drinking water standards for protection of public health (e.g. ozone, particulate matter in outdoor air; chromium, chloroform or benzene in water); establishment of cleanup levels for hazardous waste site remediation; development of fish consumption advisories for pregnant women and general population (e.g. PCBs, mercury); assessment of risks and benefits of different alternative fuels for sound energy policy development (e.g. oxygenated gasoline, biodiesel); and estimation of health risks associated with pesticide residues in food. The estimated risk is a function of exposure and toxicity. The regulatory risk assessment follows a four-step paradigm using qualitative and/or quantitative approaches. In quantitative risk assessment using either deterministic or probabilistic approaches, the risk estimates pertaining to an exposure scenario is particularly useful when comparing a number of exposure or risk reduction measures among one another as an optimization protocol to determine the best economically viable option for protection of public health and the environment. The four steps of risk assessment are i) hazard identification; ii) toxicity (or dose- response) assessment; iii) exposure assessment; and iv) risk characterization, which are described below in detail. The emphasis is given in documenting the resources necessary to successfully perform each step.

1. In the hazard identification step, a scientific weight of evidence analysis is performed to determine whether a particular substance or chemical is or is not causally linked to any particular health effect at environmentally relevant concentrations. Hazard identification is performed to determine whether, and to what degree, toxic effects in one setting will occur in other settings. The evidence comes from human but also animal studies.
2. Toxicity or dose-response assessment takes the toxicity data gathered in the hazard identification step from animal studies and exposed human population studies and describes the quantitative relationship between the amount of exposure to a chemical (or dose) and the extent of toxic injury or disease (or response). Generally, as the dose of a chemical increases, the toxic response increases either in the severity of the injury or in the incidence of response in the affected population.
3. The magnitude of exposure is determined by measuring or estimating the amount of an agent to which humans are exposed (i.e. exposure concentration) and the magnitude of dose (or intake) is estimated by taking the magnitude, frequency, duration, and route of exposure into account. Exposure assessments may consider past, present, and future exposures.
4. In the last step, a hazard quotient (HQ) as an indicator of risks associated with health effects other than cancer and excess cancer risk as the incremental probability of an exposed person developing cancer over a lifetime, are calculated by integrating toxicity and exposure information.

The improvement in the scientific quality and validity of health risk estimates depends on advancements in our understanding of human exposure to, and toxic effects associated with, chemicals present in environmental and occupational settings. Risk assessments are important for informed regulatory decision-making in environmental sustainability and to ensure that costs associated with different technological alternatives are scientifically justified and protest public health. Risk assessment helps federal agencies and risk management decision makers arrive at informed decisions about actions to take to protect human health from environmental hazards. Although significant uncertainties remain, this risk assessment methodology has been extensively peer-reviewed, is widely used and understood by the scientific community, and continues to expand and evolve as scientific knowledge advances.

**Risk management** (Figure 8.7) is distinct from risk assessment, and involves the integration of risk assessment with other considerations, such as economic, social, or legal concerns, to reach regulatory decisions regarding the need for and practicability of implementing various risk reduction activities.




Source: EPA Office of Research and Development.

FIGURE 8.7

Risk Assessment and Management.

EPA. (2013). Attachment 6: Useful terms and definitions for explaining risk. Accessed August 31, 2019 at https://semspub.epa.gov/work/HQ/174688.pdf.

Finally, **risk communication** consists of the formal and informal processes of communication among various parties who are potentially at risk from or are otherwise interested in the threatening agent/action. It matters a great deal how a given risk is communicated and perceived: do we have a measure of control, or are we subject to powerful unengaged or arbitrary forces?

## 8.5 Case Study: The Love Canal Disaster

One of the most famous and important examples of groundwater pollution in the U.S. is the Love Canal tragedy in Niagara Falls, New York. It is important because the pollution disaster at Love Canal, along with similar pollution calamities at that time (Times Beach, Missouri and Valley of Drums, Kentucky), helped to create Superfund, a federal program instituted in 1980 and designed to identify and clean up the worst of the hazardous chemical waste sites in the U.S.

Love Canal is a neighborhood in Niagara Falls named after a large ditch (approximately 15 m wide, 3–12 m deep, and 1600 m long) that was dug in the 1890s for hydroelectric power. The ditch was abandoned before it actually generated any power and went mostly unused for decades, except for swimming by local residents. In the 1920s Niagara Falls began dumping urban waste into Love Canal, and in the 1940s the U.S. Army dumped waste from World War II there, including waste from the frantic effort to build a nuclear bomb. Hooker Chemical purchased the land in 1942 and lined it with clay. Then, the company put into Love Canal an estimated 21,000 tons of hazardous chemical waste, including the carcinogens benzene, dioxin, and PCBs in large metal barrels and covered them with more clay. In 1953, Hooker sold the land to the Niagara Falls school board for $1, and included a clause in the sales contract that both described the land use (filled with chemical waste) and absolved them from any future damage claims from the buried waste. The school board promptly built a public school on the site and sold the surrounding land for a housing project that built 200 or so homes along the canal banks and another 1,000 in the neighborhood During construction, the canal's clay cap and walls were breached, damaging some of the metal barrels.

Eventually, the chemical waste seeped into people's basements, and the metal barrels worked their way to the surface. Trees and gardens began to die; bicycle tires and the rubber soles of children's shoes disintegrated in noxious puddles. From the 1950s to the late 1970s, residents repeatedly complained of strange odors and substances that surfaced in their yards. City officials investigated the area, but did not act to solve the problem. Local residents allegedly experienced major health problems including high rates of miscarriages, birth defects, and chromosome damage, but studies by the New York State Health Department disputed that. Finally, in 1978 President Carter declared a state of emergency at Love Canal, making it the first human-caused environmental problem to be designated that way. The Love Canal incident became a symbol of improperly stored chemical waste. Clean up of Love Canal, which was funded by Superfund and completely finished in 2004, involved removing contaminated soil, installing drainage pipes to capture contaminated groundwater for treatment, and covering it with clay and plastic. In 1995, Occidental Chemical (the modern name for Hooker Chemical) paid $102 million to Superfund for cleanup and $27 million to Federal Emergency Management Association for the relocation of more than 1,000 families. New York State paid $98 million to EPA and the US government paid $8 million for pollution by the Army. The total clean up cost was estimated to be $275 million.

The Love Canal tragedy helped to create Superfund, which has analyzed tens of thousands of hazardous waste sites in the U.S. and cleaned up hundreds of the worst ones. Nevertheless, over 1,000 major hazardous waste sites with a significant risk to human health or the environment are still in the process of being cleaned.

# 8.6 Resources

## Summary

Environmental health is concerned with preventing disease, death and disability by reducing exposure to adverse environmental conditions and promoting behavioral change. It focuses on the direct and indirect causes of diseases and injuries, and taps resources inside and outside the health care system to help improve health outcomes. Environmental health risks can be grouped into two broad categories. Traditional hazards related to poverty and lack of development affect developing countries and poor people most. Modern hazards, caused by development that lacks environmental safeguards, such as urban (outdoor) air pollution and exposure to agro-industrial chemicals and waste, prevail in industrialized countries, where exposure to traditional hazards is low. Each year contaminated water and poor sanitation contribute to 5.4 billion cases of diarrhea worldwide and 1.6 million deaths, mostly among children under the age of five. Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7 percent of global burden of disease. Emerging and reemerging diseases have been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts. Antibiotic resistance is a global problem. New forms of antibiotic resistance can cross international boundaries and spread between continents. Environmental toxicology is the scientific study of the health effects associated with exposure to toxic chemicals and systems occurring in the natural, work, and living environments; the management of environmental toxins and toxicity; and the development of protections for humans, animals, and plants. Environmental contaminants are chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources.

## Review Questions

1. Define environmental health.
2. Define the following terms: carcinogenic, mutagenic, teratogenic, endocrine disruptor.
3. Describe the difference between acute and chronic effect.
4. Give two examples of emerging diseases.
5. Define modern hazards.
6. What are the three main routes of exposure a chemical can get into our body?
7. What are the two types of mercury people are usually exposed to?

# 8.7 References

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# Supplementary Images

Legesse, T. (2013). Bayee Chumee and Bayee Waqo. [JPG]. Retrieved from https://commons.wikimedia.org/wiki/Category:AIDS_in_Africa#/media/File:12._Bayee_Chumee_and_Bayee_Waqo_(10995486103).jpg

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# CHAPTER 9 Food and Hunger

## Chapter Outline



FIGURE 9.1

By learning skills like composting, crop diversification, organic pesticide production, seed multiplication and agro-forestry farmers in Malawi are increasing their ability to feed their families over the long term.

## Learning Outcomes

After studying this chapter, you should be able to:

- Understand the major drivers of food insecurity
- Recognize the role of women in food and nutritional security
- Classify key food and nutritional sources
- Identify benefits and risks of genetic engineering

# 9.1 Food Security

Progress continues in the fight against hunger, yet an unacceptably large number of people still lack the food they need for an active and healthy life (World Bank, 2009). The latest available estimates indicate that about 795 million people in the world – just over one in nine –still go to bed hungry every night, and an even greater number live in poverty (defined as living on less than $1.25 per day). Poverty—not food availability—is the major driver of food insecurity. Improvements in agricultural productivity are necessary to increase rural household incomes and access to available food but are insufficient to ensure food security. Evidence indicates that poverty reduction and food security do not necessarily move in tandem. The main problem is lack of economic (social and physical) access to food at national and household levels and inadequate nutrition (or hidden hunger). Food security not only requires an adequate supply of food but also entails availability, access, and utilization by all—men and women of all ages, ethnicities, religions, and socioeconomic levels.

## From Agriculture to Food Security

Agriculture and food security are inextricably linked (World Bank, 2015). The agricultural sector in each country is dependent on the available natural resources, as well as on national and international policy and the institutional environment that governs those resources. These factors influence women and men in their choice of crops and levels of potential productivity. Agriculture, whether domestic or international, is the only source of food both for direct consumption and as raw material for refined foods. Agricultural production determines food availability. The stability of access to food through production or purchase is governed by domestic policies, including social protection policies and agricultural investment choices that reduce risks (such as droughts) in the agriculture production cycle. Yet the production of food is not the only goal of agricultural systems that also produce feed for livestock and fuel. Therefore, demand for and policies related to feed and fuel also influence food availability and access.

Staple grains are the main source of dietary energy in the human diet and are more likely to be available through national and international markets, even in developing countries, given their storage and transport characteristics. Fruits, vegetables, livestock, and aquaculture products are the key to micronutrient, that is, vitamins and minerals, sufficiency. However, most of these products are more perishable than grains, so that in the poorest countries where lack of infrastructure, such as cold storage and refrigerated transport, predicates short food chains, local agriculture determines the diversity of diets. Food security can become a reality only when the agricultural sector is vibrant.

### Women's Role in Food and Nutritional Security

Agricultural interventions are most likely to affect nutrition outcomes when they involve diverse and complementary processes and strategies that redirect the focus beyond agriculture for food production and toward broader consideration of livelihoods, women's empowerment, and optimal intrahousehold uses of resources (World Bank, 2009). Successful projects are those that invest broadly in improving human capital, sustain and increase the livelihood assets of the poor, and focus on gender equality. Women are crucial in the translation of the products of a vibrant agriculture sector into food and nutritional security for their households. They are often the farmers who cultivate food crops and produce commercial crops alongside the men in their households as a source of income. When women have an income, substantial evidence indicates that the income is more likely to be spent on food and children's needs. Women are generally responsible for food selection and preparation and for the care and feeding of children. Women are the key to food security for their households. In rural areas the availability and use of time by women is also a key factor in the availability of water for good hygiene, firewood collection, and frequent feeding of small children. In sub-Saharan Africa transportation of supplies for domestic use—fetching fuelwood and water—is largely done by women and girls on foot. Changes in the availability of natural resources, due to the depletion of natural resources and/or impacts of climate change, can compromise food security by further constraining the time available to women. Water degradation and pollution can force women to travel farther to collect water, reduce the amount they collect, and compromise hygiene practices in the household. Recognizing women's needs for environmental resources, not only for crop production but also for fuel and water, and building these into good environmental management can release more time for women to use on income generation, child care, and leisure.

## Food security

Food security is essentially built on four pillars: **availability**, **access**, **utilization** and **stability** (Bora, Ceccacci, Delgado & Townsend, 2011). An individual must have access to sufficient food of the right dietary mix (quality) at all times to be food secure. Those who never have sufficient quality food are **chronically food insecure**.

### TABLE 9.1:

| WHAT IS FOOD SECURITY? |
|---|
| **Food security** exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets dietary needs and food preferences for an active and healthy life.<br>It includes the following dimensions: **availability**: the availability of sufficient quantities of appropriate quality; **access**: access by individuals to adequate resources for acquiring appropriate foods for a nutritious diet on a regular basis; **utilization**: utilization of food through adequate diet, clean water, sanitation and health care to reach a nutritional well-being where all physiological needs are met; **stability**: a population, household or individual must have access to food at all times and should not risk losing access as a consequence of sudden shocks or cyclical events.<br>Certain groups are particularly vulnerable to food insecurity, including women (especially low income pregnant and lactating women), victims of conflict, the ill, migrant workers, low-income urban dwellers, the elderly, and children under five. |

The definition of food security is often applied at varying levels of aggregation, despite its articulation at the individual level. The importance of a pillar depends on the level of aggregation being addressed. At a global level, the important pillar is **food availability** (World Bank, 2009). Does global agricultural activity produce sufficient food to feed all the world's inhabitants? The answer today is yes, but it may not be true in the future given the impact of a growing world population, emerging plant and animal pests and diseases, declining soil productivity and environmental quality, increasing use of land for fuel rather than food, and lack of attention to agricultural research and development, among other factors.

When food security is analyzed at the national level, an understanding not only of national production is important, but also of the country's **access** to food from the global market, its foreign exchange earnings, and its citizens' consumer choices. Food security analyzed at the household level is conditioned by a household's own food production and household members' ability to purchase food of the right quality and diversity in the market place. However, it is only at the individual level that the analysis can be truly accurate because only through understanding who consumes what can we appreciate the impact of sociocultural and gender inequalities on people's ability to meet their nutritional needs.

The third pillar, food **utilization**, essentially translates the food available to a household into nutritional security for its members. One aspect of utilization is analyzed in terms of distribution according to need. Nutritional standards exist for the actual nutritional needs of men, women, boys, and girls of different ages and life phases (that is, pregnant women), but these "needs" are often socially constructed based on culture. For example, in South Asia evidence shows that women eat after everyone else has eaten at a meal and are less likely than men in the same household to consume preferred foods such as meats and fish. **Hidden hunger** commonly results from poor food utilization: that is, a person's diet lacks the appropriate balance of macro- (calories) and micronutrients (vitamins and minerals). Individuals may look well nourished and consume sufficient calories but be deficient in key micronutrients such as vitamin A, iron, and iodine.

When food security is analyzed at the national level, an understanding not only of national production is important, but also of the country's access to food from the global market, its foreign exchange earnings, and its citizens' consumer choices. Food security analyzed at the household level is conditioned by a household's own food production and household members' ability to purchase food of the right quality and diversity in the market place. However, it is only at the individual level that the analysis can be truly accurate because only through understanding who consumes what can we appreciate the impact of sociocultural and gender inequalities on people's ability to meet their nutritional needs.

**Malnutrition** is economically costly: it can cost individuals 10 percent of their lifetime earnings and nations 2 to 3 percent of gross domestic product (GDP) in the worst-affected countries (Alderman 2005). Achieving food security is even more challenging in the context of HIV and AIDS. HIV affects people's physical ability to produce and use food, reallocating household labor, increasing the work burden on women, and preventing widows and children from inheriting land and productive resources (Izumi 2006).

Public policies, written from a human rights perspective, recognize the interrelatedness of all basic rights and assist in the identification of those whose rights are not fully realized. In this way they facilitate corrective action and appropriate strategies to enable equal protection for all. Equal representation and active engagement of both women and men in the policymaking processes are required so that their varying needs and priorities are appropriately targeted. More often than not, however, access to the legal system may be more problematic for women than men, but technical and financial support is also needed if institutions that advance and implement women's rights are to fulfill their mandate.

### Recognizing the Role of Women Can Improve Food and Nutritional Security

Food security is a primary goal of sustainable agricultural development and a cornerstone for economic and social development (World Bank, 2009). Women play vital and often unacknowledged role in agriculture. Gender-based inequalities all along the food production chain "from farm to plate" impede the attainment of food and nutritional security. Maximizing the impact of agricultural development on food security entails enhancing women's roles as agricultural producers as well as the primary caretakers of their families.

## Obesity

Obesity means having too much body fat. It is not the same as overweight, which means weighing too much. Obesity has become a significant global health challenge, yet is preventable and reversible. Over the past 20 years, a global overweight/obesity epidemic has emerged, initially in industrial countries and now increasingly in low- and middle-income countries, particularly in urban settings, resulting in a triple burden of undernutrition, micronutrient deficiency, and overweight/obesity. There is significant variation by region; some have very high rates of undernourishment and low rates of obesity, while in other regions the opposite is true (Figure 9.2).

However, obesity has increased to the extent that the number of overweight people now exceeds the number of underweight people worldwide. The economic cost of obesity has been estimated at $2 trillion, accounting for about 5 percent of deaths worldwide. Almost 30 percent of the world's population, or 2.1 billion people, are overweight or obese, 62 percent of whom live in developing countries.

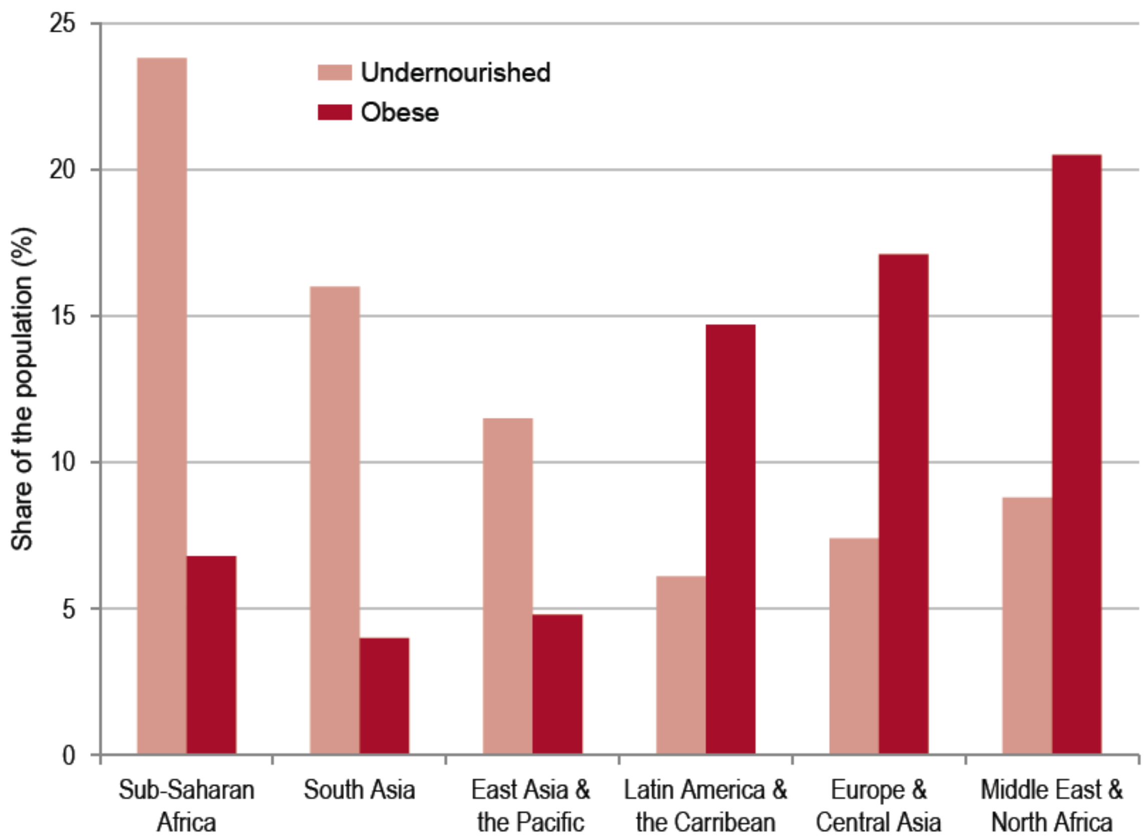



FIGURE 9.2

Obesity and undernourishment by region.

World Bank. (2015). Ending poverty and hunger by 2030: An agenda for the global food system. Wash- ington, DC. © World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/21771. Available under Creative Commons Attribution License 3.0 IGO

Obesity accounts for a growing level and share of worldwide noncommunicable diseases, including diabetes, heart disease, and certain cancers that can reduce quality of life and increase public health costs of already underresourced developing countries. The number of overweight children is projected to double by 2030. Driven primarily by increasing availability of processed, affordable, and effectively marketed food, the global food system is falling short with rising obesity and related poor health outcomes. Due to established health implications and rapid increase in prevalence, obesity is now a recognized major global health challenge, and no national success stories in curbing its growth have so far been reported. Eating a variety of healthful foods promotes good physical health and provides energy for growth and activity. Many common diseases and their symptoms can be prevented or helped with healthful eating. Knowing what your body needs can help you choose foods to meet those needs.

**Nutrients, Energy, and Building Materials**

Nutrients are chemical elements or compounds that the body needs for normal functioning and good health (CK12, 2009). There are six main classes of nutrients: carbohydrates, proteins, lipids, water, vitamins, and minerals. The body needs these nutrients for three basic purposes: energy, building materials, and control of body processes.

A steady supply of energy is needed by cells for all body functions. Carbohydrates, proteins, and lipids provide this energy. Chemical bonds in molecules of these nutrients contain energy. When the bonds are broken during digestion to form simpler molecules, the energy is released. Energy is measured in units called kilocalories (kcal), commonly referred to as Calories.

Molecules that make up the body are continuously broken down or used up, so they must be replaced. Some nutrients, particularly proteins, provide the building materials for this purpose. Other nutrients—including proteins, vitamins, and minerals—are needed to regulate body processes. One way is by helping to form enzymes. Enzymes are compounds that control the rate of chemical reactions in the body.

Nutrients can be classified in two groups based on how much of them the body needs:

- **Macronutrients** are nutrients that the body needs in relatively large amounts. They include carbohydrates, proteins, lipids, and water.
- **Micronutrients** are nutrients the body needs in relatively small amounts. They include vitamins and minerals.

The exact amount of a macronutrient an individual needs depends on many factors, including gender and age. Recommended daily intakes of three macronutrients for young people of both genders are shown in **Table** 9.2.

TABLE 9.2: Recommended Daily Intakes of Carbohydrates, Proteins, and Water

| Gender And Age | Carbohydrates(grams/day) | Proteins(grams/day) | Water*(liters/day) |
|---|---|---|---|
| Males 9–13 years | 130 | 34 | 2.4 |
| 14–18 years | 130 | 52 | 3.3 |
| Females 9–13years | 130 | 34 | 2.1 |
| 14–18 years | 130 | 46 | 2.3 |

- Includes water in foods as well as beverages

**Carbohydrates** are classified as either simple or complex, based on the number of saccharides they contain.

Simple carbohydrates contain just one or two saccharides. They are all sugars. Examples of sugars in the diet include fructose, which is found in fruit, and lactose, which is found in milk. The main function of simple carbohydrates is to provide the body with energy. One gram of carbohydrate provides four kilocalories of energy. Glucose is the sugar that is used most easily by cells for energy. It circulates in the blood, providing energy to cells throughout the body. Glucose is the only source of energy used by the brain.

Complex carbohydrates, called polysaccharides, generally contain many saccharides. They include starches and fiber. Starches are found in plant foods such as vegetables and grains. They are broken down during digestion to form sugars that provide energy. Fiber consists of indigestible starches and other materials such as cellulose. It is present in all plant foods.

Fiber may be soluble or insoluble.

- Soluble fiber dissolves in water as it passes through the large intestine. It helps form substances that keep blood levels of glucose stable and blood levels of harmful lipids low (see below).
- Insoluble fiber does not dissolve but attracts water as it passes through the large intestine. This helps keep waste moist and moving easily through the intestine.

**Proteins** play many vital roles in the body, including:

- Making up the majority of muscle tissue.
- Regulating many body processes.
- Forming antibodies that destroy bacteria and other "foreign invaders."
- Regulating the salt-water and acid-base balance in body fluids.
- Transporting nutrients and other vital substances in the blood.

Dietary proteins are broken down during digestion to provide the amino acids that cells need to make proteins for the body. Twenty different amino acids are needed for this purpose. Ten of these amino acids can be synthesized by cells from simple components. The other ten cannot be synthesized and must be obtained from foods. They are called essential amino acids because they are essential in the diet.

Proteins that contain all ten essential amino acids are referred to as complete proteins. They are found in animal foods such as milk and meat. Proteins that are missing one or more essential amino acids are referred to as incomplete proteins. They are found in plant foods such as legumes and rice. By eating a variety of different plant foods containing incomplete proteins, you can include all ten essential amino acids in your diet.

If you eat more protein than needed for the synthesis of new proteins by cells, the excess is used for energy or stored as fat. One gram of protein provides four kilocalories of energy. This is the same amount of energy that one gram of carbohydrate provides.

**Lipids,** or fatty acids, are organic compounds that consist of repeating units of carbon, hydrogen, and oxygen. They provide the body with energy. The heart and skeletal muscles rely mainly on lipids for fuel. One gram of lipids provides nine kilocalories of energy, more than twice the amount provided by carbohydrates or proteins. Lipids have several other functions as well. Lipids form an insulating sheath around nerve cells that helps nerve messages travel more quickly. Lipids also help form substances that regulate blood pressure, blood clotting, and blood lipid levels. In addition, lipids make up the membranes that surround cells.

The term fat is often used interchangeably with the term lipid, but fats are actually a particular type of lipid, called **triglycerides**, in which three fatty acids are bound to a compound called glycerol. Fats are important in the body. They are the main form in which the body stores energy. Stored body fat is called adipose tissue. Stored fat not only provides an energy reserve but also cushions and protects internal organs. In addition, stored fat insulates the body and helps prevent heat loss in cold weather.

Although lipids and fats are necessary for life, they may be harmful if they are present in the blood at high levels. Both triglycerides and the lipid called cholesterol are known to damage blood vessels if their concentrations in the blood are too high. By damaging blood vessels, triglycerides and cholesterol also increase the risk of heart disease.

Lipids are classified as either saturated fatty acids or unsaturated fatty acids. This classification is based on the number of chemical bonds between carbon atoms in lipid molecules.

- **Saturated fatty acids** have only single bonds between carbon atoms. This gives them properties that make them unhealthful. Their amount in the diet should be kept as low as possible. If consumed in excess, they contribute to high blood levels of cholesterol and triglycerides. Saturated fatty acids are found in animal foods, such as meat, whole milk, and eggs.

- **Unsaturated fatty acids** have at least one double bond between carbon atoms. This gives them properties that make them more healthful. Eaten in appropriate amounts, they may help lower blood levels of cholesterol and triglycerides and decrease the risk of cardiovascular disease. They are found mainly in plant foods.

The human body can synthesize all but two of the fatty acids it needs: omega-3 fatty acids and omega-6 fatty acids. Both are unsaturated fatty acids. They are called essential fatty acids because they must be present in the diet. They are found in salmon, vegetable oil, flaxseed, eggs, and whole grains. Small amounts of these two fatty acids may help lower blood pressure as well as blood levels of harmful lipids.

Unsaturated fatty acids known as trans fatty acids (or trans fats), are manufactured from plant oils and do not occur naturally. They are added to foods to extend their shelf life. Trans fats have properties like saturated fats and may increase risk of cardiovascular disease. They should be avoided in balanced eating. Many manufacturers no longer add trans fats to food products, and their use in restaurants has been banned in some cities.

### Water

You may not think of water as a food, but it is a nutrient. Water is essential to life because it is the substance within which all the chemical reactions of life take place. An adult can survive only a few days without water.

Water is lost from the body in exhaled air, sweat, and urine. Dehydration occurs when a person does not take in enough water to replace the water that is lost. Symptoms of dehydration include headaches, low blood pressure, and dizziness. If dehydration continues, it can quickly lead to unconsciousness and even death. When you are very active, particularly in the heat, you can lose a great deal of water in sweat. To avoid dehydration, you should drink extra fluids before, during, and after exercise.

Taking in too much water—especially without consuming extra salts—can lead to a condition called hyponatremia. In this condition, the brain swells with water, causing symptoms such as nausea, vomiting, headache, and coma. Hyponatremia can be fatal, so it requires emergency medical care.

### Balanced Eating

Balanced eating is a way of eating that promotes good health. It includes eating several medium-sized meals regularly throughout the day. It also includes eating the right balance of different foods to provide the body with all the nutrients it needs. How much of these foods should you eat to get the right balance of nutrients? Two tools for choosing foods that provide balanced nutrition are MyPyramid and nutrition labels on food packages.

### MyPyramid

MyPyramid was developed by the U.S. Food and Drug Administration. It shows how much you should eat each day of foods in different food groups. MyPyramid is shown in **Figure** 9.3. You can visit the mypyramid.gov website for more details or to customize MyPyramid for your gender, age, activity level, and other factors.

#### Guidelines for Using MyPyramid

**1.** The six colored bands represent six food groups:

- Brown = Grains—At least half should be whole grains.
- Green = Vegetables—Choose a variety of vegetables, including dark green and orange vegetables, dry beans and peas.
- Red = Fruits—Include a variety of fruits, and consume whole fruits instead of fruit juices.
- Yellow = Oils—Choose mainly unsaturated nut and vegetable oils.
- Blue = Milk—Dairy products should be low-fat or fat-free choices.
- Purple = Meat and Beans—Choose fish and low-fat meats, as well as beans, peas, nuts, and seeds.


FIGURE 9.3

MyPyramid is visual representation of how much you should eat each day of foods in different food groups.

**2.** The width of each colored band shows the proportion of food that should come from each food group.

**3.** The figure climbing stairs reminds you to balance food with exercise: 30–60 min/day of moderate-to-vigorous activity is recommended for most people.

Each food group represented by a colored band in MyPyramid is a good source of nutrients. The wider the band, the more you should eat from that food group. For example, the brown band is widest, so the largest proportion of foods should come from the grains group. The white tip of MyPyramid represents foods that should be eaten only in very small amounts or very infrequently. They include foods such as ice cream and potato chips that contain few nutrients and may contribute excess kilocalories to the diet.

The figure "walking" up the side of MyPyramid in **Figure** 9.3 represents the role of exercise in balanced eating. Daily exercise helps you burn any extra energy that you consume in foods. The more active you are, the more energy you use. Light activities, such as golfing, typically use only a few hundred kilocalories per hour. Strenuous activities, such as running, may use over 900 kilocalories per hour.

Harvard University recently developed an alternative healthy eating pyramid, which is shown in **Figure** 9.4. It differs from MyPyramid in placing more emphasis on exercise and a greater focus on eating fruits, vegetables, and healthy plant oils. It moves red meats and starchy, low-nutrient foods, such as white bread and white rice, to the category of foods to eat in very limited amounts. Some experts think that the Harvard pyramid is less confusing than MyPyramid and represents an even healthier way of eating.

### MyPlate

In June 2011, the United States Department of Agriculture replaced My Pyramid with **MyPlate.** MyPlate depicts the relative portions of various food groups. See http://www.choosemyplate.gov for further information.

The following guidelines accompany MyPlate:

1. Balancing Calories

- Enjoy your food, but eat less.
- Avoid oversized portions.

2. Foods to Increase

- Make half your plate fruits and vegetables.
- Make at least half your grains whole grains.
- Switch to fat-free or low-fat (1%) milk.


FIGURE 9.4
Healthy eating pyramid.
Choosemyplate. (2019). Choose my plate. Department of agriculture. Retrieved from https://www.choosemyplate.gov/


FIGURE 9.5
MyPlate is a visual guideline for balanced eating, replacing MyPyramid in 2011.
Choosemyplate.gov. (2019). Choose my plate. Department of agriculture. Retrieved from https://www.choosemyplate.gov/

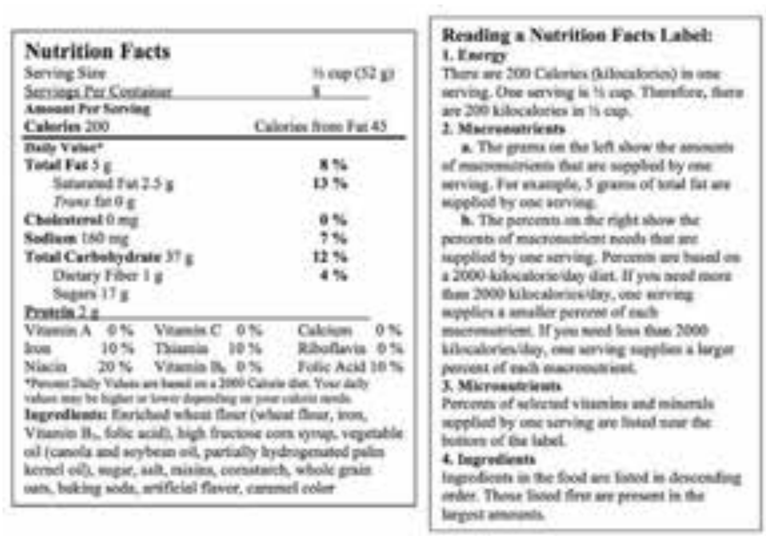
3. Foods to Reduce

- Compare sodium in foods like soup, bread, and frozen meals [U+2015] and choose the foods with lower numbers.
- Drink water instead of sugary drinks.

### Food Labels

Packaged foods are required by law to carry a nutrition facts label, like the one in **Figure** 9.6, showing the nutrient content and ingredients in the food.

Reading nutrition facts labels can help you choose foods that are high in nutrients such as protein and low in nutrients such as fat. Nutrition facts labels can also help you choose foods that are nutrient dense. Nutrient density is the ratio of nutrient content, measured in grams, to total energy content in kilocalories.


Nutrition Facts
Serving Size ½ cup (52 g)
Servings Per Container 8
Amount Per Serving
Calories 200 Calories from Fat 45
Daily Value*
Total Fat 5 g 8 %
Saturated Fat 2.5 g 13 %
*Trans* fat 0 g
Cholesterol 0 mg 0 %
Sodium 160 mg 7 %
Total Carbohydrate 37 g 12 %
Dietary Fiber 1 g 4 %
Sugars 17 g
Protein 2 g
Vitamin A 0 % Vitamin C 0 % Calcium 0 %
Iron 10 % Thiamin 10 % Riboflavin 0 %
Niacin 20 % Vitamin B₆ 0 % Folic Acid 10 %
*Percent Daily Values are based on a 2000 Calorie diet. Your daily values may be higher or lower depending on your calorie needs.
Ingredients: Enriched wheat flour (wheat flour, iron, Vitamin B₁, folic acid), high fructose corn syrup, vegetable oil (canola and soybean oil, partially hydrogenated palm kernel oil), sugar, salt, raisins, cornstarch, whole grain oats, baking soda, artificial flavor, caramel color

Reading a Nutrition Facts Label:
1. Energy
There are 200 Calories (kilocalories) in one serving. One serving is ½ cup. Therefore, there are 200 kilocalories in ½ cup.
2. Macronutrients
a. The grams on the left show the amounts of macronutrients that are supplied by one serving. For example, 5 grams of total fat are supplied by one serving.
b. The percents on the right show the percents of macronutrient needs that are supplied by one serving. Percents are based on a 2000-kilocalorie/day diet. If you need more than 2000 kilocalories/day, one serving supplies a smaller percent of each macronutrient. If you need less than 2000 kilocalories/day, one serving supplies a larger percent of each macronutrient.
3. Micronutrients
Percents of selected vitamins and minerals supplied by one serving are listed near the bottom of the label.
4. Ingredients
Ingredients in the food are listed in descending order. Those listed first are present in the largest amounts.

FIGURE 9.6
Nutrition facts label.

TABLE 9.3: Consider the following two foods:

| | |
|---|---|
| 15g/300 kcal = 0.05 g/kcal | 10g/120 kcal = 0.08 g/kcal |
| Nutrient Density: | Nutrient Density: |
| Energy: 300 kcal | Energy: 120 kcal |
| Protein: 15 g | Protein: 10 g |
| **Food A** | **Food B** |

In terms of protein, Food B is more nutrient dense than Food A, because it provides more protein per kilocalorie. Eating nutrient-dense foods helps you to get enough of each nutrient without taking in too many kilocalories.

Reading the ingredients list on food labels can also help you choose healthful foods for balanced eating. At the top of the list, look for ingredients such as whole grains, vegetables, and fruits. These are foods you need the most of in a balanced diet. Avoid foods that contain processed ingredients, such as white flour or white rice. Processing removes nutrients. As a result, processed foods generally supply fewer nutrients than whole foods, even when they have been enriched or fortified with added nutrients.

### Vitamins and Minerals

Unlike the major macronutrients, micronutrients—including vitamins and minerals—do not provide energy (CK12, 2009). Nonetheless, adequate amounts of micronutrients are essential for good health. The needed amounts generally can be met with balanced eating. However, many people do not eat enough of the right foods to meet their requirements. They may need vitamin or mineral supplements to increase their intake of micronutrients.

#### Vitamins

**Vitamins** are organic compounds that are needed by the body to function properly. There are 13 vitamins that humans need. They are described in **Table** 9.4, which also includes recommended daily vitamin intakes for teens.

Vitamins play many roles in good health, ranging from helping maintain vision to helping form red blood cells. Many vitamins are components of enzymes. For example, vitamin K is a component of enzymes involved in blood clotting. Several vitamins, including vitamins C and E, act as antioxidants. An antioxidant is a compound that neutralizes chemicals called free radicals. Free radicals are produced naturally during cellular activities and may cause some types of cancer. Neutralizing free radicals makes them harmless.

Some vitamins, including vitamin $B_6$, are produced by bacteria that normally live in the intestines, where they help digest food. Vitamin D is synthesized in the skin when it is exposed to UV radiation in sunlight. Most other vitamins must be obtained from foods because the body is unable to synthesize them. Good food sources of vitamins are listed in the table below. They include whole grains, vegetables, fruits, milk, and nuts.

Consuming inadequate amounts of vitamins can cause deficiency diseases. For example, consuming inadequate amounts of vitamin D causes soft bones. In children this is called rickets. It can cause permanent bone deformities. Consuming inadequate amounts of vitamin A may lead to blindness and visual impairment.

Consuming too much of some vitamins can also be dangerous. Overdoses of vitamins can cause problems ranging from diarrhea to birth defects and even death.

Vitamins are either fat-soluble or water-soluble. This determines whether they can accumulate in the body and lead to overdoses.

- Vitamins A, D, E, and K are fat soluble. Excess intakes of these vitamins are stored in fatty tissues of the body. Because they are stored in the body, they can build up to toxic levels, especially if they are taken improperly in supplements.
- Vitamin C and all the B vitamins are water soluble. Excess amounts of these vitamins are excreted in the urine, so they are unlikely to reach toxic levels in the body.
- Recommended daily intakes not established; figures given are adequate daily intakes.

**TABLE 9.4:** Vitamins

| Vitamin (Chemical Name) | Functions in the Body | Good Food Sources |
|---|---|---|
| (Retinoids)Vitamin A | Needed for good vision, reproduction, and fetal development | Carrots, spinach, milk, eggs |
| (Thiamine)Vitamin B1 | Helps break down macronutrients; essential for proper functioning of nerves | Whole wheat, peas, beans, fish, peanuts, meats |
| (Riboflavin)Vitamin B2 | Helps the body process amino acids and fats; acts as antioxidant | Milk, liver, green leafy vegetables, almonds, soybeans |
| (Niacin)Vitamin B3 | Helps release energy from macronutrients; needed for healthy skin and nerves | Beets, beef liver, pork, turkey, fish, sunflower seeds, peanuts |
| (Pantothenic Acid)Vitamin B5, | Helps form critical enzymes for synthesis of macronutrients | Whole grains, legumes, eggs, meat |
| (Pyridoxine) Vitamin B6 | Forms enzymes needed for amino acid synthesis and energy storage | Cereals, yeast, liver, fish, avoca-does, nuts, green beans |
| (Biotin)Vitamin B7 | Enables synthesis of fatty acids; helps store energy; keeps level of blood sugar stable | None |
| (Folate)Vitamin B9 | Needed to make red blood cells | Liver, green leafy vegetables, dried beans and peas |
| (Cyanocobalamin)Vitamin B12 | Needed for normal functioning of nervous system and formation of blood | Meat, liver, milk, shellfish, eggs |

TABLE 9.4: (continued)

| | | |
|---|---|---|
| (Ascorbic Acid) Vitamin C | Needed to make many biological chemicals; acts as antioxidant | Citrus fruits such as oranges, red peppers, broccoli, kiwi |
| (Ergocalciferol and Cholecalciferol) Vitamin D | Helps maintain blood levels of calcium; needed for healthy bones and teeth | Salmon, tuna, eggs, mushrooms |
| (Tocopherol) Vitamin E | Acts as antioxidant; protects cell membranes from LDL cholesterol damage | Vegetable oils, nuts, green leafy vegetables, whole grains, fish |
| (Naphthoquinone) Vitamin K | Helps transport calcium; helps blood clot | Kale, spinach, Brussels sprouts, milk, eggs, soy products |

**Minerals**

Dietary minerals are chemical elements that are essential for body processes. Minerals are inorganic, meaning they do not contain carbon. Minerals needed by humans in relatively large amounts (greater than 200 mg/day) are listed in **Table** below. Minerals not listed in the table are called trace minerals because they are needed in very small amounts. Trace minerals include chromium, iodine, iron, molybdenum, selenium, and zinc.

TABLE 9.5: Minerals

| Mineral Name (Symbol) | Functions in the Body | Good Food Sources |
|---|---|---|
| (Ca) Calcium | Needed for nerve and muscle action; builds bone and teeth; helps blood clot | Milk, soy milk, green leafy vegetables, sardines |
| (Cl) Chloride | Helps maintain water and pH balance; helps form stomach acid | Table salt, most processed foods |
| (Mg) Magnesium | Needed to form several enzymes | Whole grains, green leafy vegetables, nuts, seeds |
| (P) Phosphorus | Component of bones, teeth, lipids, and other important molecules in the body | Meat, poultry, whole grains |
| (K) Potassium | Needed for muscle and nerve function; helps maintain salt-water balance in body fluids | Meats, grains, orange juice, potatoes, bananas |
| (Na) Sodium | Needed for muscle and nerve function; helps maintain salt-water balance in body fluids | Table salt, most processed foods |
| (S) Sulfur | Necessary component of many proteins | Whole grains, meats, seafood, eggs |

Minerals play many important roles in the body. Most are found in the blood and cytoplasm of cells, where they control basic functions. For example, calcium and potassium regulate nerve and muscle activity. Several minerals, including zinc, are components of enzymes. Other minerals, including calcium, form the bulk of teeth and bones. Recommended daily intakes not established; figures given are adequate daily intakes.

Minerals cannot be synthesized by the body. Good food sources of minerals include dairy products, green leafy vegetables, and legumes. Mineral deficiencies are uncommon, but inadequate intakes of a few minerals may lead to health problems. For example, an inadequate intake of calcium may contribute to osteoporosis, a disease in which bones become brittle and break easily. A deficiency in iodine (necessary for the thyroid hormones that regulate growth) may lead to goiter. Iron deficiency is the primary cause of anemia.

Some minerals may be toxic in excess, but overdoses of most minerals are uncommon. Overdoses are more likely when mineral supplements are taken. Salt (sodium chloride) is added to many foods, so the intake of sodium may be too high in many people. Too much sodium in the diet can cause high blood pressure in some individuals.

### Other Micronutrients

Recently, new micronutrients called phytochemicals have been found in plants. They occur primarily in colorful fruits and vegetables. Thousands of phytochemicals have been discovered, and some have already been shown to lower the risk of certain diseases. For example, the phytochemical lutein helps reduce the risk of macular degeneration, an eye disease that leads to blindness. Lutein is found in many yellow and orange fruits and vegetables. Several phytochemicals, including some found in berries and cherries, have proven to be powerful antioxidants.

# 9.3 Biotechnology and Genetic Engineering

**Agricultural biotechnology** is a range of tools, including traditional breeding techniques, that alter living organisms, or parts of organisms, to make or modify products; improve plants or animals; or develop microorganisms for specific agricultural uses (USDA, 2019). Modern biotechnology today includes the tools of genetic engineering. **Genetic engineering** is the name for certain methods that scientists use to introduce new traits or characteristics to an organism (known also as **genetically modified organism** or **GMO**). For example, plants may be genetically modified to produce characteristics to enhance the growth or nutritional profile of food crops.

## BENEFITS OF GENETIC ENGINEERING

Advocates of modern biotechnology and generic engineering say that the application of biotechnology in agriculture has resulted in benefits to farmers, producers, and consumers (USDA, 2019).

**Enhanced nutrition**. Advances in biotechnology may provide consumers with foods that are nutritionally-enriched (Figure 9.8) or longer-lasting, or that contain lower levels of certain naturally occurring toxicants present in some food plants. Developers are using biotechnology to try to reduce saturated fats in cooking oils, reduce allergens in foods, and increase disease-fighting nutrients in foods. Biotechnology may also be used to conserve natural resources, enable animals to more effectively use nutrients present in feed, decrease nutrient runoff into rivers and bays, and help meet the increasing world food and land demands.

FIGURE 9.8

White rice and Golden rice. Genetically engineered "Golden Rice" contains up to 35 $\mu$g β-carotene per gram of rice. International Rice Research Institute (IRRI). (2011). Golden Rice grain compared to white rice grain in screenhouse of Golden Rice plants. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Golden_Rice.jpg. Available under the Creative Commons Attribution 2.0

**Cheaper and more manageable production.** Biotechnology may provide farmers with tools that can make production cheaper and more manageable. For example, some biotechnology crops can be engineered to tolerate specific herbicides, which make weed control simpler and more efficient. Other crops have been engineered to be resistant to specific plant diseases and insect pests, which can make pest control more reliable and effective, and/or can decrease the use of synthetic pesticides. These crop production options can help countries keep pace with demands for food while reducing production costs.

**Improved pest control.** Biotechnology has helped to make both insect pest control and weed management safer and easier while safeguarding crops against disease. For example, genetically engineered insect-resistant cotton has allowed for a significant reduction in the use of persistent, synthetic pesticides that may contaminate groundwater and the environment. In terms of improved weed control, herbicide-tolerant soybeans, cotton, and corn enable the use of reduced-risk herbicides that break down more quickly in soil and are non-toxic to wildlife and humans.

## CONCERNS ABOUT GENETICALLY MODIFIED ORGANISMS

The complexity of ecological systems presents considerable challenges for experiments to assess the risks and benefits and inevitable uncertainties of GMOs (Maghari & Ardekani, 2011). Assessing such risks is extremely difficult, because both natural and human-modified systems are highly complex, and fraught with uncertainties that may not be clarified until long after an experimental introduction has been concluded. Critics of GMOs warn that the cultivation of GMOs, with their potential benefits and hazards to the environment, should be carefully considered within broader ecosystems.

**Interbreeding with native species.** When the genetically modified organisms are allowed to breed with the organisms which are not genetically engineered, then these organisms may affect the genetic of non-genetically engineered organisms. Due to this reason the whole ecological system might get affected. The main concern is that genetically modified organisms might lead the non-GM organisms to extinction and reduce biodiversity.

**GM food labeling.** In order to verify whether people have been harmed over the years by consuming GMF, specifically in countries like the US where people's dietary are mainly composed of such products, the law for mandatory labeling is highly required. However, the labeling is not just about health issue rather, it is about consumer rights to make an informed choice. Although a consensual system on GMO labeling is crucial, it seems unlikely that an internationally agreed labeling system can be set up in proximate future. Nevertheless, different GMO labeling schemes have been established in different countries, ranging from stringent to extremely lenient or even non existent legislations. While the EU has established strict labeling regulations, in the US, Canada and Argentina, three big producers of GMO food, such laws have been put forward but not enacted by these governments. A proper labeling represents the "GM" word, along with additional information on changed characteristics and the external source of the inserted gene. Negative labeling such as "GM free" is not suggested, because it might give the wrong impression to the consumers. The law for compulsory labeling of genetically modified food products has been established in more than 40 countries. Surveys commissioned by different organizations have shown that people across the world are seeking for transparency and consumer choice and believe that compulsory labeling scheme on GM ingredients is highly required: 88% Canadians, 92% Americans and 93% French.

**Consumers right to choose.** The International Federation of Organic Agriculture Movement has made stringent efforts to keep GMOs out of organic production, yet some US organic farmers have found their corn (maize) crops, including seeds, to contain detectable levels of genetically engineered DNA (Godheja, 2013). The organic movement is firm in its opposition to any use of GMOs in agriculture, and organic standards explicitly prohibit their use. The farmers, whose seed is contaminated, have been under rigid organic certification, which assures that they did not use any kind of genetically modified materials on their farms. Any trace of GMOs must have come from outside their production areas. While the exact origin is unclear at this time, it is most likely that the pollution has been caused by pollen drift from GMO-fields in surrounding areas. However, the contamination may have also come from the seed supply. Seed producers, who intended to supply GMO-free seed, have also been confronted with genetic contamination and cannot guarantee that their seed is 100% GMO-free.

**Ecological long-term effects.** The Bt corn produces wind-borne pollen that kills the caterpillars of the Monarch butterfly. If the life cycles of this butterfly are disrupted, the Monarch butterflies might be endangered. Agriculture might be affected as the weeds acquire the modified genes to become more competitive. The risk of the evolution of common plant viruses to become more resistant or form new strains will be greatly increased. If genetic modification is carried out extensively, new viruses with greater potential to harm humankind may evolve, and the probability of this occurring can be quite high.

**Human health risk.** At least some of the genes used in GMOs may not have been used in the food supply before, so GM foods may pose a potential risk for human health. Much of the GM production currently grown worldwide is destined for animal feed. The FAO has concluded that risks to human and animal health from the use of GM crops and enzymes derived from GM microorganisms as animal feed are negligible. But scientists acknowledge that little is known about the long-term safety of consuming food made from GM products. WHO recognizes the need for continued safety assessments on genetically modified foods before they are marketed to prevent risks to human health and for continued monitoring.

The potential of GM crops to be allergenic is one of the main suspected adverse health effects. Many scientific data indicate that animals fed by GMO crops have been harmed or even died. Rats exposed to transgenic potatoes or soy had abnormal young sperm; cows, goats, buffalo, pigs and other livestock grazing on Bt-maize, GM cottonseed and certain biotech corn showed complications including early deliveries, abortions, infertility and also many died. However, this is a controversial subject as studies conducted by company producing the biotech crops did not show any negative effects of GM crops on mice.

Although Agri-biotech companies do not accept the direct link between the GMOs consumption and human health problems, there are some examples given by the opponents (Maghari, B. M., & Ardekani, A. M., 2011). For example: The foodborne diseases such as soy allergies have increased over the past 10 years in USA and UK and an epidemic of Morgellons disease in the US. There are also reports on hundreds of villagers and cotton handlers who developed skin allergy in India. Recent studies have revealed that *Bacillus thuringiensis* corn expresses an allergenic protein which alters overall immunological reactions in the body. The aforementioned reports performed by independent GMO researchers have lead to a concern about the risks of GMOs and the inherent risks associated with the genetic technology.

**Intellectual property rights** are one of the important factors in the current debate on GMOs. The GM crops are patented by Agri-business companies leading to monopolization of the global agricultural food and controlling distribution of the world food supply (Maghari, B. M., & Ardekani, A. M., 2011). Social activists believe that the hidden reason why biotech companies are eager to produce GMO crops is because they can be privatized, unlike ordinary crops which are the natural property of all humanity. It is argued for example that to achieve this monopoly, the large Agri-biotech company, Monsanto, has taken over small seed companies in the past 10 years and has become the biggest Agri-biotech Corporation in the world. The patent right for vegetable forms of life also affect the livelihoods of family farmers as they are required to sign a contract preventing them from saving and re-planting the seeds, thus they have to pay for seeds each year.

Critics, thus advise that the risks for the introduction of a GMOs into each new ecosystem need to be examined on a case-by-case basis, alongside appropriate risk management measures, such as through the precautionary principle in the Cartagena Protocol and the IPPC's Pest Risk Assessment (PRA).

# 9.4 Resources

## Summary

Progress continues in the fight against hunger, yet an unacceptably large number of people still lack the food they need for an active and healthy life. About 795 million people in the world still go to bed hungry every night, and an even greater number live in poverty. Poverty is the major driver of food insecurity. Improvements in agricultural productivity are necessary to increase rural household incomes and access to available food but are insufficient to ensure food security. Food security is essentially built on four pillars: availability, access, utilization and stability. Women are crucial in the translation of the products of a vibrant agriculture sector into food and nutritional security for their households. They are often the farmers who cultivate food crops and produce commercial crops alongside the men in their households as a source of income. Over the past 20 years, a global obesity epidemic has emerged. Due to established health implications and rapid increase in prevalence, obesity is now a recognized major global health challenge, and no national success stories in curbing its growth have so far been reported. Genetic engineering is the name for methods that scientists use to introduce new traits or characteristics to an organism. Advocates say that application of genetic engineering in agriculture has resulted in benefits to farmers, producers, and consumers. Critics advise that the risks for the introduction of a GMO into each new ecosystem need to be examined on a case-by-case basis, alongside appropriate risk management measures.

## Review Questions

1. Explain the four dimensions of food security.
2. How are *poverty* and *food security* related?
3. Define *hidden hunger*.
4. Why is women's role in agriculture important in food security?
5. What percentage of overweight people live in developed countries?
6. Do you think that biotechnology should be used to change the genetic makeup of the plants and animals that humans consume for food? What might be the benefits and risks? Do you think the benefits outweigh the risks?

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## Supplementary Images

International Rice Research Institute (IRRI). (2011). Golden Rice grain compared to white rice grain in screenhouse of Golden Rice plants. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Golden_Rice.jpg. Available under the Creative Commons Attribution 2.0

# CHAPTER 10 Conventional and Sustainable Agriculture

## Chapter Outline



FIGURE 10.1
Women farmers planting a rice field in West Sumatra.

## Learning Outcomes

After studying this chapter, you should be able to:

- Describe the components of soils
- Discuss how land use affects global ecosystem conditions
- Identify environmental effects of pesticides
- Recognize the relationship between exposure to POPs and human health
- Explain alternative practices in farming and soil management

## 10.1 Soil Profiles and Processes

### What is Soil?

The word " **soil**" has been defined differently by different scientific disciplines (Theis & Tomkin, 2015). In agriculture and horticulture, soil generally refers to the medium for plant growth, typically material within the upper meter or two (see Figure 10.2).

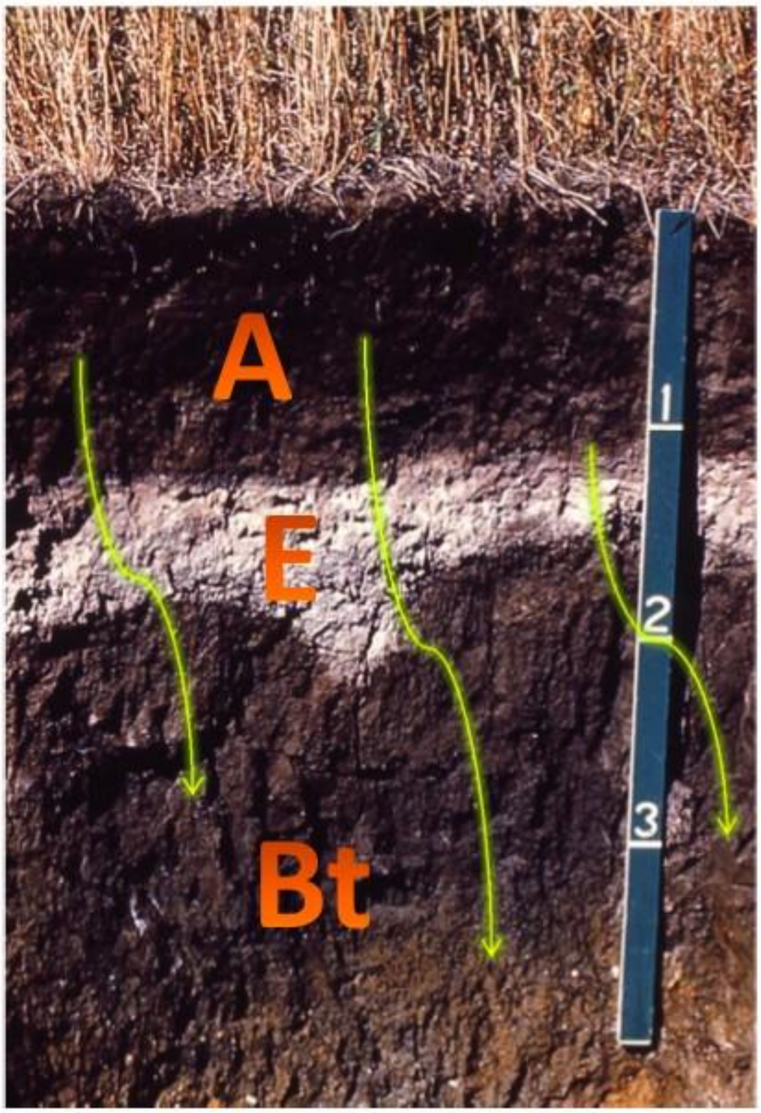


FIGURE 10.2
Soil Profile. Photograph shows a soil profile from South Dakota with A, E, and Bt horizons. The yellow arrows symbolize translocation of fine clays to the Bt horizon. The scale is in feet. Source: University of Idaho and modified by D. Grimley.

We will use this definition in this chapter. In common usage, the term soil is sometimes restricted to only the dark topsoil in which we plant our seeds or vegetables. In a more broad definition, civil engineers use the term soil for any unconsolidated (soft when wet) material that is not considered bedrock. Under this definition, soil can be as much as several hundred feet thick! Ancient soils, sometimes buried and preserved in the subsurface, are referred to as **paleosols** (see Figure 10.3) and reflect past climatic and environmental conditions.

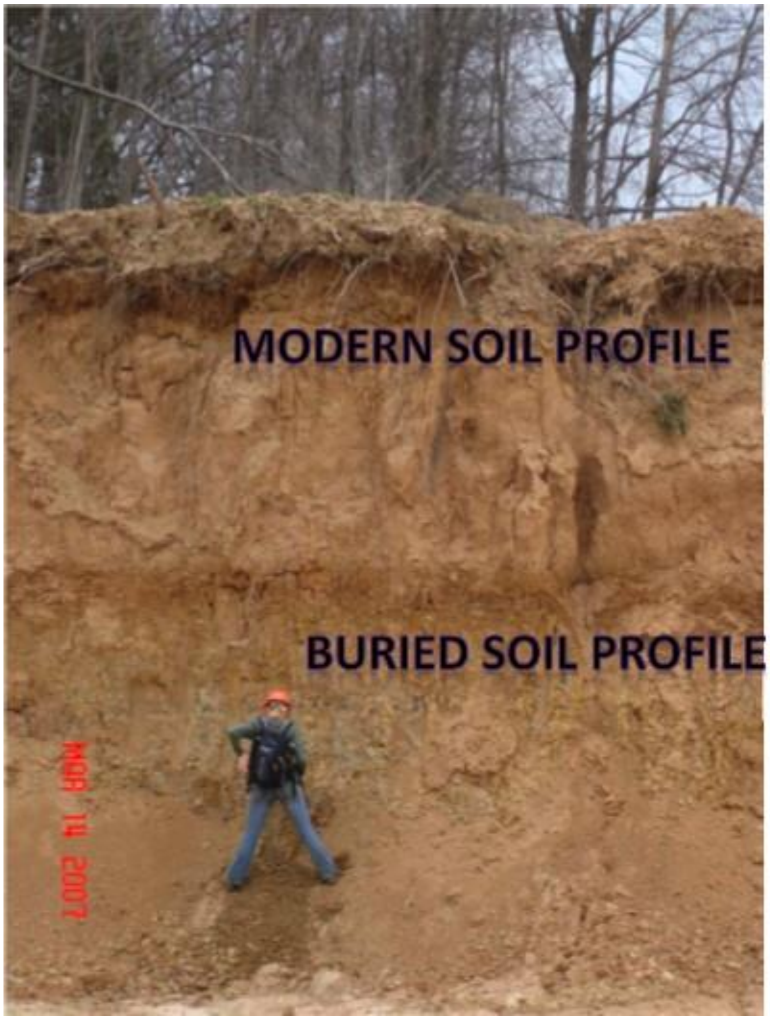


FIGURE 10.3

Modern versus Buried Soil Profiles. A buried soil profile, or paleosol (above geologist 's head), represents soil development during the last interglacial period. A modern soil profile (Alfisol) occurs near the land surface. Source: D. Grimley.

From a somewhat philosophical standpoint, soil can be viewed as the interface between the atmosphere and the earth's crust, and is sometimes referred to as the skin of the earth. Soil also incorporates aspects of the biosphere and the hydrosphere. From a physical standpoint, soil contains solid, liquid, and gaseous phases. The solid portion of the soil consists predominantly of mineral matter, but also contains organic matter (humus) and living organisms. The pore spaces between mineral grains are filled with varying proportions of water and air.

### Importance of Soil

Soil is important to our society as it provides the foundation for most of the critical aspects of civilization. Our building structures and homes, food, agricultural products, and wood products all rely on soil. Forests, prairies, and wetlands all have a dependence on soil. Of course, soil is also a critical component for terrestrial life on earth, including most animals, plants, and many microorganisms.

Soil plays a role in nearly all natural cycles on the earth's surface. Global cycling of key nutrients, such as Carbon (C), Nitrogen (N), Sulfur (S), and Phosphorous (P), all pass through soil. In the hydrologic cycle, soil helps to mediate the flow of precipitation from the land surface into the groundwater or can control stormwater runoff into lakes, streams, bays, and oceans. Soil microorganisms or microflora can help to modify or destroy environmental pollutants.

## Soil Forming Factors

The fundamental factors that affect soil genesis can be categorized into five elements: climate, organisms, relief, parent material, and time. One could say that the landscape *relief*, *climate*, and *organisms* dictate the local soil environment, and act together to cause weathering and mixing of the soil *parent material* over *time*. The soil forming factors are interrelated and interdependent, but considered independently they provide a useful framework for discussion and categorization.

As soil is formed it often has distinct layers, which are formally described as "horizons." Upper horizons (labeled as the A and O horizons) are richer in organic material and so are important in **plant growth**, while deeper layers (such as the B and C horizons) retain more of the original features of the bedrock below.

### Climate

The role of climate in soil development includes aspects of temperature and precipitation. Soils in very cold areas with permafrost conditions (*Gelisols*) tend to be shallow and weakly developed due to the short growing season. Organic rich surface horizons are common in low-lying areas due to limited chemical decomposition. In warm, tropical soils (*Ultisols*, *Oxisols*), other factors being equal, soils tend to be thicker, with extensive leaching and mineral alteration. In such climates, organic matter decomposition and chemical weathering occur at an accelerated rate.

### Organisms

Animals, plants, and microorganisms all have important roles in soil development processes, in providing a supply of organic matter, and/or in nutrient cycling. Worms, nematodes, termites, ants, gophers, moles, crayfish, etc. all cause considerable mixing of soil and help to blend soil, aerate and lighten the soil by creating porosity, and create characteristic natural soil structure over time. Animal life, such as insects and mammals, can cause irregularities in the soil horizons.

Plant life provides much organic matter to soil and helps to recycle nutrients with uptake by roots in the subsurface. The type of plant life that occurs in a given area, such as types of trees or grasses, depends on the climate, along with parent material and soil type. So there are clearly feedbacks among the soil forming factors. With the annual dropping of leaves and needles, trees tend to add organic matter to soil surfaces, helping to create a thin, organic-rich A or O horizon over time. Grasses, on the other hand, have a considerable root mass, in addition to surficial organic material, that is released into the soil each fall for annuals and short-lived perennials. For this reason, grassland soils (*Mollisols*) have much thicker A horizons with higher organic matter contents, and are more agriculturally productive than forest soils. Grasses release organic matter to soils that is more rich in base cations, whereas leaf and needle litter result in release of acids into the soil.

Microorganisms aid in the oxidation of organic residues and in production of humus material. They also play a role in iron oxidation-reduction cycles, fine-grained mineral dissolution (providing nutrients to soil solutions), and mineral neoformation. New research is continually expanding our knowledge of the role of microorganisms in plant growth, nutrient cycling, and mineral transformations.

### Relief (Topography and Drainage)

The local landscape can have a surprisingly strong effect on the soils that form on site. The local topography can have important microclimatic effects as well as affecting rates of soil erosion. In comparison to flat regions, areas with steep slopes overall have more soil erosion, more runoff of rainwater, and less water infiltration, all of which lead to more limited soil development in very hilly or mountainous areas. In the northern hemisphere, south-facing slopes are exposed to more direct sunlight angles and are thus warmer and drier than north-facing slopes. The cooler, moister north-facing slopes have a more dynamic plant community due to less evapotranspiration and, consequently, experience less erosion because of plant rooting of soil and have thicker soil development.

Soil drainage affects iron oxidation-reduction states, organic matter accumulation and preservation, and local vegetation types. Well-drained soils, generally on hills or sideslopes, are more brownish or reddish due to conversion of ferrous iron ($Fe^{2+}$) to minerals with ferric ($Fe^{3+}$) iron. More poorly drained soils, in lowland, alluvial plains or upland depressions, tend more be more greyish, greenish-grey (gleyed), or dark colored, due to iron reduction (to $Fe^{2+}$) and accumulation and preservation of organic matter in areas tending towards anoxic. Areas with poor drainage also tend to be lowlands into which soil material may wash and accumulate from surrounding uplands, often resulting in overthickened A or O horizons. In contrast, steeply sloping areas in highlands may experience erosion and have thinner surface horizons.

### Parent Material

The parent material of a soil is the material from which the soil has developed, whether it be river sands, lake clays, windblown loess, shoreline deposits, glacial deposits, or various types of bedrock. In youthful soils, the parent material has a clear connection to the soil type and has significant influence. Over time, as weathering processes deepen, mix, and alter the soil, the parent material becomes less recognizable as chemical, physical, and biological processes take their effect. The type of parent material may also affect the rapidity of soil development. Parent materials that are highly weatherable (such as volcanic ash) will transform more quickly into highly developed soils, whereas parent materials that are quartz-rich, for example, will take longer to develop. Parent materials also provide nutrients to plants and can affect soil internal drainage (e.g. clay is more impermeable than sand and impedes drainage).

### Time

In general, soil profiles tend to become thicker (deeper), more developed, and more altered over time. However, the rate of change is greater for soils in youthful stages of development. The degree of soil alteration and deepening slows with time and at some point, after tens or hundreds of thousands of years, may approach an equilibrium condition where erosion and deepening (removals and additions) become balanced. Young soils (<10,000 years old) are strongly influenced by parent material and typically develop horizons and character rapidly. Moderate age soils (roughly 10,000 to 500,000 years old) are slowing in profile development and deepening, and may begin to approach equilibrium conditions. Old soils (>500,000 years old) have generally reached their limit as far as soil horizonation and physical structure, but may continue to alter chemically or mineralogically.

To be sure, soil development is not always continual. Geologic events can rapidly bury soils (landslides, glacier advance, lake transgression), can cause removal or truncation of soils (rivers, shorelines) or can cause soil renewal with additions of slowly deposited sediment that add to the soil (wind or floodplain deposits). Biological mixing can sometimes cause soil regression, a reversal or bump in the road for the normal path of increasing development over time.

# 10.2 Soil-Plant Relations

## Natural Processes

Soil plays a key role in plant growth (Theis & Tomkin, 2015). Beneficial aspects to plants include providing physical support, heat, water, nutrients, and oxygen. Heat, light, and oxygen are also obtained by the atmosphere, but the roots of many plants also require oxygen. Elemental nutrients, dissolved in soil water solution, are derived from soil minerals and organic material (see Figure 10.4).

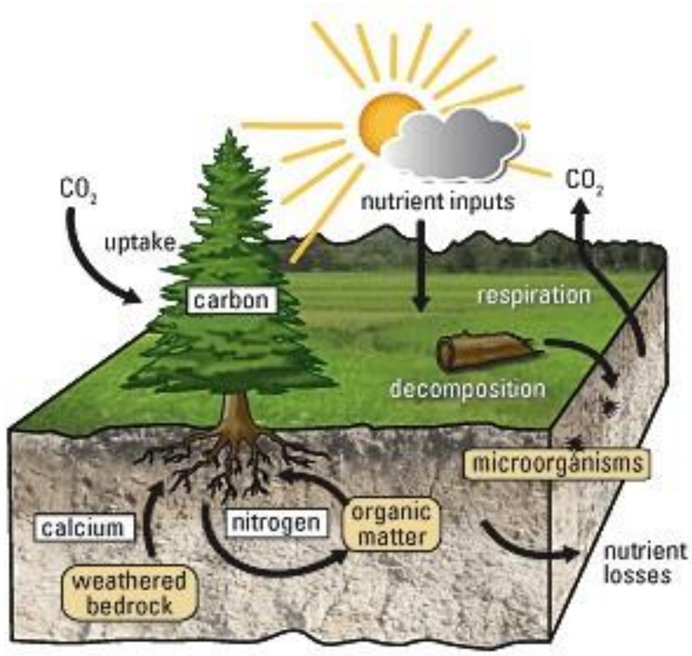


FIGURE 10.4

Soil-Plant Nutrient Cycle. Figure illustrates the uptake of nutrients by plants in the forest" soil ecosystem. Source: U.S. Geological Survey.

Plants mainly obtain nutrients from dissolved soil solutions. Though many aspects of soil are beneficial to plants, excessively high levels of trace metals (either naturally occurring or anthropogenically added) or applied herbicides can be toxic to some plants.

The ratio of solids/water/air in soil is also critically important to plants for proper oxygenation levels and water availability. Too much porosity with air space, such as in sandy or gravelly soils, can lead to less available water to plants, especially during dry seasons when the water table is low. Too much water, in poorly drained regions, can lead to anoxic conditions in the soil, which may be toxic to some plants. Hydrophytic vegetation can handle anoxic conditions and is thus suitable to poorly drained soils in wetland areas.

## Nutrient Uptake by Plants

Several elements obtained from soil are considered essential for plant growth. Macronutrients, including C, H, O, N, P, K, Ca, Mg, and S, are needed by plants in significant quantities. C, H, and O are mainly obtained from the atmosphere or from rainwater. These three elements are the main components of most organic compounds, such as proteins, lipids, carbohydrates, and nucleic acids. Oxygen generally serves as an electron acceptor and is required by roots of many plants. The other six elements (N, P, K, Ca, Mg, and S) are obtained by plant roots from the soil and are variously used for protein synthesis, chlorophyll synthesis, energy transfer, cell division, enzyme reactions, and osmotic or ionic regulation.

Micronutrients are essential elements that are needed only in small quantities, but can still be limiting to plant growth since these nutrients are not so abundant in nature. Micronutrients include iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), zinc (Zn), and copper (Cu). There are some other elements that tend to aid plant growth but are not absolutely essential.

Micronutrients and macronutrients are desirable in particular concentrations and can be detrimental to plant growth when concentrations in soil solution are either too low (limiting) or too high (toxicity). Elemental nutrients are useful to plants only if they are in an extractable form in soil solutions, such as an exchangeable cation, rather than in a solid mineral grain. As nutrients are used up in the microenvironment surrounding a plant's roots, the replenishment of nutrients in soil solution is dependent on three aspects: (a) the rate of dissolution/alteration of soil minerals into elemental constituents, (b) the release rate of organically bound nutrients, and (c) the rate of diffusion of nutrients through the soil solution to the area of root uptake.

Many nutrients move through the soil and into the root system as a result of concentration gradients, moving by diffusion from high to low concentrations. However, some nutrients are selectively absorbed by the root membranes, such that elemental concentrations of solutions within plants may differ from that in soil solutions. Most nutrients exist as exchangeable cations that are acquired by roots from the soil solution—rather than from mineral or particle surfaces. Inorganic chemical processes and organic processes, such as the action of soil microorganisms, can help to release elemental nutrients from mineral grains into the soil environment.

## 10.3 Conventional Agriculture

The long-term viability of our current food production system is being questioned for many reasons (NAL, 2007). The news media regularly present us with the paradox of starvation amidst plenty—including pictures of hungry children juxtaposed with supermarket ads. Possible adverse environmental impacts of agriculture and increased incidence of food borne illness also demand our attention. "Farm crises" seem to recur with regularity.

The prevailing agricultural system, variously called "conventional farming," "modern agriculture," or "industrial farming" has delivered tremendous gains in productivity and efficiency. Food production worldwide has risen in the past 50 years; the World Bank estimates that between 70 percent and 90 percent of the recent increases in food production are the result of conventional agriculture rather than greater acreage under cultivation. U.S. consumers have come to expect abundant and inexpensive food.

Conventional farming systems vary from farm to farm and from country to country. However, they share many characteristics: rapid technological innovation; large capital investments in order to apply production and management technology; large-scale farms; single crops/row crops grown continuously over many seasons; uniform high-yield hybrid crops; extensive use of pesticides, fertilizers, and external energy inputs; high labor efficiency; and dependency on agribusiness. In the case of livestock, most production comes from confined, concentrated systems.

Both positive and negative consequences have come with the bounty associated with industrial farming. Some concerns about contemporary agriculture are presented below.

While considering these concerns, keep the following in mind:

a. interactions between farming systems and soil, water, biota, and atmosphere are complex—we have much to learn about their dynamics and long term impacts;
b. most environmental problems are intertwined with economic, social, and political forces external to agriculture;
c. some problems are global in scope while others are experienced only locally;
d. many of these problems are being addressed through conventional, as well as alternative, agricultural channels;

### Ecological Concerns

Agriculture profoundly affects many ecological systems. Negative effects of current practices include the following:

**Decline in soil productivity** can be due to wind and water erosion of exposed topsoil; soil compaction; loss of soil organic matter, water holding capacity, and biological activity; and **salinization** of soils and irrigation water in irrigated farming areas. **Desertification** due to overgrazing is a growing problem, especially in parts of Africa. Agricultural practices have been found to contribute to non-point source water pollutants that include: sediments, salts, fertilizers (nitrates and phosphorus), pesticides, and manures.

Pesticides from every chemical class have been detected in groundwater and are commonly found in groundwater beneath agricultural areas; they are widespread in the nation's surface waters. Eutrophication and "dead zones" due to nutrient runoff affect many rivers, lakes, and oceans. Reduced water quality impacts agricultural production, drinking water supplies, and fishery production.

**Water scarcity** in many places is due to overuse of surface and ground water for irrigation with little concern for the natural cycle that maintains stable water availability.

Other environmental ills include over 400 insects and mite pests and more than 70 fungal pathogens that have become resistant to one or more pesticides; stresses on pollinator and other beneficial species through pesticide use; loss of wetlands and wildlife habitat; and reduced genetic diversity due to reliance on genetic uniformity in most crops and livestock breeds.

Agriculture's link to **global climate change** is just beginning to be appreciated. Destruction of tropical forests and other native vegetation for agricultural production has a role in elevated levels of carbon dioxide and other greenhouse gases. Recent studies have found that soils may be sources or sinks for greenhouse gases.

### Economic and Social Concerns

Economic and social problems associated with agriculture can not be separated from external economic and social pressures. As barriers to a sustainable and equitable food supply system, however, the problems may be described in the following way:

Economically, the U.S. agricultural sector includes a history of increasingly large federal expenditures and corresponding government involvement in planting and investment decisions; widening disparity among farmer incomes; and escalating concentration of agribusiness—industries involved with manufacture, processing, and distribution of farm products—into fewer and fewer hands. Market competition is limited. Farmers have little control over farm prices, and they continue to receive a smaller and smaller portion of consumer dollars spent on agricultural products.

Economic pressures have led to a tremendous loss of farms, particularly small farms, and farmers during the past few decades—more than 155,000 farms were lost from 1987 to 1997. This contributes to the disintegration of rural communities and localized marketing systems. Economically, it is very difficult for potential farmers to enter the business today. Productive farmland also has been pressured by urban and suburban sprawl—since 1970, over 30 million acres have been lost to development.

### Impacts on Human Health

As with many industrial practices, potential health hazards are often tied to farming practices. Under research and investigation currently is the sub-therapeutic use of antibiotics in animal production, and pesticide and nitrate contamination of water and food. Farmer worker health is also a consideration in all farming practices.

### Philosophical Considerations

Historically, farming played an important role in our development and identity as a nation. From strongly agrarian roots, we have evolved into a culture with few farmers. Less than two percent of Americans now produce food for all U.S. citizens. Can sustainable and equitable food production be established when most consumers have so little connection to the natural processes that produce their food? What intrinsically American values have changed and will change with the decline of rural life and farmland ownership?

World population continues to grow. According to recent United Nations population projections, the world population will grow to 9.4 billion in 2050, 10.4 billion in 2100, and 10.8 billion by 2150, and will stabilize at slightly under 11 billion around 2200. The rate of population increase is especially high in many developing countries. In these countries, the population factor, combined with rapid industrialization, poverty, political instability, and large food imports and debt burden, make long-term food security especially urgent.

# 10.4 Pests and Pesticides

## Pests and Pesticides

Pests are living organisms that occur where they are not wanted or that cause damage to crops or humans or other animals (EPA, 2015). A pesticide is a term for any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Though often misunderstood to refer only to insecticides, the term pesticide also applies to herbicides, fungicides, and various other substances used to control pests. By their very nature, most pesticides create some risk of harm—pesticides can cause harm to humans, animals, or the environment because they are designed to kill or otherwise adversely affect living organisms. At the same time, pesticides are useful to society—they can kill potential disease-causing organisms and control insects, weeds, and other pests.

Pest Control is a Common Tool

The management of pests is an essential part of agriculture and public health and an important tool in the maintenance of power lines and roads. Chemical pest management has helped to reduce losses in agriculture and to limit human exposure to disease vectors. Chemical pesticides can be effective, fast acting, adaptable to all crops and situations. When first applied, a plant protection strategy based exclusively on chemical pesticides can result in impressive production gains. However, despite these initial gains, excessive use of insecticides has proven to be ecologically unsound, leading to the destruction of natural enemies, the increase of pest resistance pest resurgence and outbreaks of secondary pests.

These consequences have often resulted in higher production costs and lost markets due to undesirable pesticide residue levels, as well as environmental and human health costs– side-effects which have been unevenly distributed. Despite the fact that the lion's share of chemical pesticides are applied in developed countries, 99 percent of all pesticide poisoning cases occur in developing countries where regulatory, health and education systems are weakest. Many farmers in developing countries overuse pesticides and do not take proper safety precautions because they do not understand the risks and fear smaller harvests. Making matters worse, developing countries seldom have strong regulatory systems for dangerous chemicals: pesticides banned or restricted in industrialized countries are used widely in developing countries. Farmers' perceptions of appropriate pesticide use vary by setting and culture. Prolonged exposure to pesticides has been associated with several chronic and acute health effects like non-Hodgkin's lymphoma, leukemia, as well as cardiopulmonary disorders, neurological and hematological symptoms, and skin diseases.

## Table 10.1:

| BOX 1. HUMAN HEALTH, ENVIRONMENTAL, AND ECONOMIC EFFECTS OF PESTICIDE USE IN POTATO PRODUCTION IN ECUADOR |
|---|
| The International Potato Center (CIP) conducted an interdisciplinary and inter-institutional research intervention project dealing with pesticide impacts on agricultural production, human health, and the environment in Carchi, Ecuador. Carchi is the most important potato-growing area in Ecuador, where smallholder farmers dominate production. They use tremendous amounts of pesticides for the control of the Andean potato weevil and the late blight fungus. Virtually all farmers apply class 1b highly toxic pesticides using hand pump backpack sprayers. Research concerning pesticides has examined: neurological impacts on farmers and their families; poisoning incidence; studies of farmers' attitudes, knowledge, and practices; economic impacts; and contamination of ground and surface water, clothing and body surfaces, food, and farmers' homes. Intervention activities have included: farmer field schools, community meetings analyzing personal and household exposure pathways, promotion of safety measures, radio announcements, educational programs, and stakeholder workshops. The study found that the health problems caused by pesticides are severe and are affecting a high percentage of the rural population. Despite the existence of technology and policy solutions, Government policies continue to promote the use of pesticides. The study conclusions concurred with those by the pesticide industry, "that any company that could not ensure the safe use of highly toxic pesticides should remove them from the market and that it is almost impossible to achieve safe use of highly toxic pesticides among small farmers in developing countries." |

## POPs

Persistent Organic Pollutants or POPs are a group of chemicals that includes 12 organic compounds (Aldrin, chlordane, DDT, dieldrin, dioxins, endrin, furans, heptachlor, hexachlorobenzene (HCB), mirex, polychlorinated biphenyls (PCBs), and toxaphene) (World Bank, 2004). These compounds have been widely used as pesticides or industrial chemicals and pose risks to human health and ecosystems. POPs have been produced and released into the environment by human activity. They have the following three characteristics:

**PERSISTENT**: POPs are chemicals that last a long time in the environment. Some may resist breakdown for years and even decades while others could potentially break down into other toxic substances.

**BIOACCUMULATIVE**: POPs can accumulate in animals and humans, usually in fatty tissues and largely from the food they consume. As these compounds move up the food chain, they concentrate to levels that could be thousands of times higher than acceptable limits.

**TOXIC**: POPs can cause a wide range of health effects in humans, wildlife and fish. They have been linked to effects on the nervous system, reproductive and developmental problems, immune response suppression, cancer, and endocrine disruption. The deliberate production and use of most POPs has been banned around the world, with some exemptions made for human health considerations (e.g. DDT for malaria control) and/or in very specific cases where alternative chemicals have not been identified. However, the unintended production and/or the current use of some POPs continue to be an issue of global concern. Even though most POPs have not been manufactured or used for decades, they continue to be present in the environment and thus potentially harmful. The same properties that originally made them so effective, particularly their stability, make them difficult to eradicate from the environment.

## POPs and Health

The relationship between exposure to environmental contaminants such as POPs and human health is complex. There is mounting evidence that these persistent, bioaccumulative and toxic chemicals (PBTs) cause long-term harm to human health and the environment (World Bank, 2004). Drawing a direct link, however, between exposure to these chemicals and health effects is complicated, particularly since humans are exposed on a daily basis to many different environmental contaminants through the air they breathe, the water they drink and the food they eat. Numerous studies link POPs with a number of adverse effects in humans. These include effects on the nervous system, problems related to reproduction and development, cancer, and genetic impacts. Moreover, there is mounting public concern over the environmental contaminants that mimic hormones in the human body. As with humans, animals are exposed to POPs in the environment through air, water and food. POPs can remain in sediments for years, where bottom-dwelling creatures consume them and who are then eaten by larger fish. Because tissue concentrations can increase or biomagnify at each level of the food chain, top predators (like largemouth bass or walleye) may have a million times greater concentrations of PBT POPs than the water itself. The animals most exposed to PBT contaminants are those higher up the food web such as marine mammals including whales, seals, polar bears, and birds of prey in addition to fish species such as tuna, swordfish and bass (Figure 10.5). Once POPs are released into the environment, they may be transported within a specific region and across international boundaries transferring among air, water, and land.

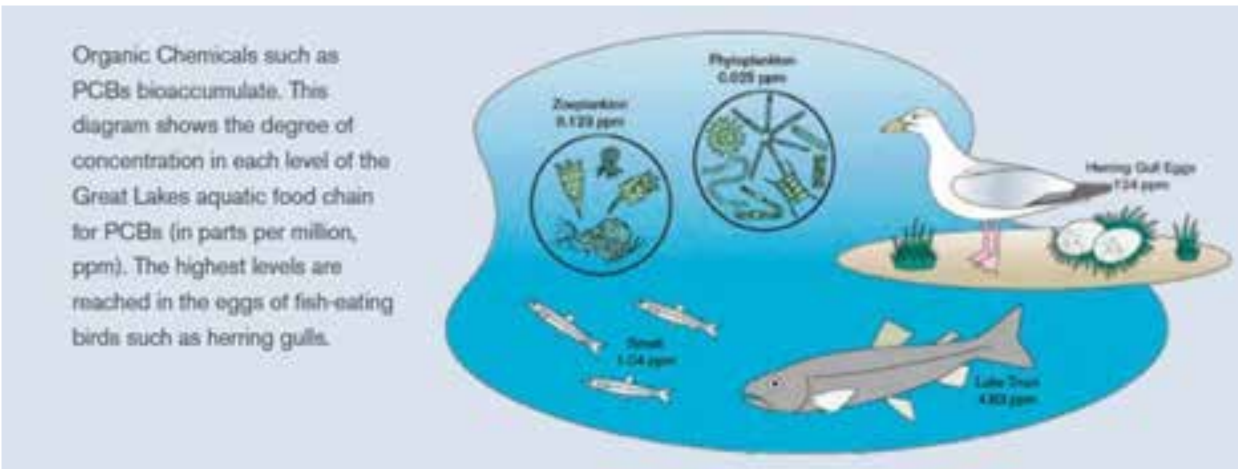


FIGURE 10.5

Bioaccumulation and biomagnification. U.S. EPA. Great Lakes: The Great Lakes Atlas: Chapter Four the Great Lakes Today - Concerns.

World Bank. (2004). Persistent organic pollutants: Backyards to borders. Washington, DC. © World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/14896. Available under Creative Commons Attribution License 3.0 (CC BY 3.0 IGO).

### "Grasshopper Effect"

While generally banned or restricted, POPs and other PBTs make their way into and throughout the environment on a daily basis through a cycle of long-range air transport and deposition called the "grasshopper" or the "global distillation" processes (World Bank, 2005). The "grasshopper" or "global distillation" processes, illustrated in Figure 10.6, begin with the release of POPs into the environment. When POPs enter the atmosphere, they can be carried with wind currents, sometimes for long distances.

Through atmospheric processes, they are deposited onto land or into water ecosystems where they accumulate and potentially cause damage. From these ecosystems, they evaporate, again entering the atmosphere, typically traveling from warmer temperatures toward cooler regions. They condense out of the atmosphere whenever the temperature drops, eventually reaching highest concentrations in circumpolar countries. Through these processes, POPs and other PBTs can move thousands of kilometers from their original source of release in a cycle that may last decades.


**FIGURE 10.6**

How POPs move throughout the environment. Source: Environment Canada. The Science and the Environment Bulletin.

## Pest Management Policies

A major policy development likely to have a significant impact on pest management in developing countries has been the **Stockholm Convention** (World Bank, 2008). The convention went into force in May 2004 and aims to phase out the POPs, including some of the most hazardous pesticides (often referred to as the "dirty dozen"). See Box 10.2 for details on the relevant protocols.

### TABLE 10.2:

**BOX 2. PEST MANAGEMENT-RELATED INTERNATIONAL CONVENTIONS**

- **The Stockholm Convention on Persistent Organic Pollutants (POP)** is a global treaty to protect human health and the environment from the chemicals that persist in the environment for extended periods of time and tend to accumulate in living tissues of various organisms. Being at the top of the food chain, humans tend to absorb the greatest concentrations of these POPs, resulting in serious disruptions of the endocrine system, suppression of the immune system, disruption of reproductive function, and various developmental abnormalities. In its initial phase, the Convention lists twelve chemicals to be phased out from production and use, among which nine are pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex and toxaphene) and three non-pesticides (dioxins, furans and polychlorinated biphenyls). The Convention came into force in May 2004 upon the 50th ratification.
- **The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade** is a global treaty adopted in 1998 to limit the potential risks posed by the production and trade in hazardous chemicals and pesticides. Countries lacking adequate infrastructure to monitor the import and use of such substances were particularly vulnerable. In the 1980s, UNEP and FAO developed voluntary codes of conduct and information exchange systems, culminating in the Prior Informed Consent (PIC) procedure introduced in 1989. The new Convention replaces this arrangement with a mandatory PIC procedure. PIC requires exporters trading in a list of hazardous substances to obtain the prior informed consent of importers before proceeding with the trade. As of 24 February 2004, the Rotterdam Convention entered into force after the 50th ratification.
- **Montreal Protocol on Ozone Depleting Substances** is an international treaty, adopted in 1987, to eliminate the production and consumption of chemicals that deplete the ozone layer. Principal among these chemicals is Methyl Bromide, widely used in agriculture as a fumigant for soil-borne pests and diseases, stored grains pests, and quarantine pests in fresh produce (fruits and vegetables, flowers).

# 10.5 Sustainable Agriculture

Some terms defy definition. "Sustainable agriculture" has become one of them. In such a quickly changing world, can anything be sustainable? What do we want to sustain? How can we implement such a nebulous goal? Is it too late? With the contradictions and questions have come a hard look at our present food production system and thoughtful evaluations of its future. If nothing else, the term "sustainable agriculture" has provided "talking points," a sense of direction, and an urgency, that has sparked much excitement and innovative thinking in the agricultural world (NAL, 2015).

"Sustainable agriculture" was addressed by Congress in the 1990 "Farm Bill". Under that law, "the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

## Organic Farming is Good for Farmers, Consumers and the Environment

Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony (NAL, 2015). Organic food is produced by farmers who emphasize the use of renewable resources and the conservation of soil and water to enhance environmental quality for future generations. Organic meat, poultry, eggs, and dairy products come from animals that are given no antibiotics or growth hormones. Organic food is produced without using most conventional pesticides; fertilizers made with synthetic ingredients or sewage sludge; bioengineering; or ionizing radiation (NAL, 2015).

Organic production, with the corresponding practices to maintain soil fertility and soil health is therefore a more benign alternative to conventional, high-value horticulture. The organic food movement has been endorsed by FAO, which maintains in a report (FAO, 2007) that organic farming fights hunger, tackles climate change, and is good for farmers, consumers, and the environment. The strongest benefits of organic agriculture are its use of resources that are independent of fossil fuels, are locally available, incur minimal agroecological stresses, and are cost effective (FAO, 2007). Some have argued that women farmers, who already rely on few external inputs, may be well positioned to become organic producers and benefit from the rising interest in organic produce.

## IPM is a Combination of Common-Sense Practices

Integrated Pest Management (IPM) refers to a mix of farmer-driven, ecologically based pest control practices that seeks to reduce reliance on synthetic chemical pesticides (Kelly, 2005). It involves (a) managing pests (keeping them below economically damaging levels) rather than seeking to eradicate them; (b) relying, to the extent possible, on non- chemical measures to keep pest populations low; and (c) selecting and applying pesticides, when they have to be used, in a way that minimizes adverse effects on beneficial organisms, humans, and the environment. It is commonly understood that applying an IPM approach does not necessarily mean eliminating pesticide use, although this is often the case because pesticides are often over-used for a variety of reasons. There are also cases where an increase in pesticide use could be justified, however pesticides should only be used when it is economically justified to do so. The IPM approach regards pesticides as mainly short-term corrective measures when more ecologically based control measures are not working adequately (sometimes referred to as using pesticides as the "last resort"). In those cases when pesticides are used, they should be selected and applied in such a manner as to minimize the amount of disruption that they cause to the agro-ecological system (i.e., to the extent possible, use products that are non-persistent, with very selective action and apply them in the most targeted possible way).

### TABLE 10.3:

| **Box 1. ORIGIN OF INTEGRATED PEST MANAGEMENT** |
| --- |
| The scientific basis of "Integrated Pest Control" evolved over a period of about 10 years, mainly among researchers at the University of California. The concept was explicitly defined in 1965 at a symposium sponsored by the Food and Agriculture Organization (FAO), of the United Nations, held in Rome, Italy. The concept of "Integrated Control," originally limited to the combination of chemical and biological control methods was greatly expanded in that symposium to become synonymous with what we now consider IPM. Concurrently, however, the concept of "Pest Management" that had been proposed by Australian ecologists in 1961, started receiving greater recognition. Publication of Geyer's Annual Review of Entomology article in 1966, a report by the US National Academy of Sciences ,and the proceedings of a conference held in North Carolina, which included participation by the original proponents of pest management from Australia, provided the impetus for that recognition. The convergence of the concepts of integrated control and pest management, and the ultimate synthesis into integrated pest management, opened a new era in the protection of agricultural crops, domestic animals, stored products, public health, and the structure of human dwellings against the attack of arthropod pests, plant and animal diseases, and weeds. |

### Biological Control

Biological control (biocontrol) is the use of one biological species to reduce populations of a different species (EPA, 1998). There has been a substantial increase in commercialization of biocontrol products, such as beneficial insects, cultivated predators and natural or non-toxic pest control products. Biocontrol is being mainstreamed to major agricultural commodities, such as cotton, corn and most commonly vegetable crops. Biocontrol is also slowly emerging in vector control in public health and in areas that for a long time mainly focused on chemical vector control in mosquito/malaria—and black fly/onchocerciasis—control programs. Successful and commercialized examples of biocontrol include **ladybugs** to depress aphid populations, **parasitic wasps** to reduce moth populations, use of the bacterium ***Bacillus thuringenensis*** to kill mosquito and moth larvae, and introduction of fungi, such as **Trichoderma**, to suppress fungal-caused plant diseases, leaf beetle (*Galerucella calmariensis*) to suppress Purple loosestrife, a noxious weed (Figure 10.9).

In all of these cases, the idea is not to completely destroy the pathogen or pest, but rather to reduce the damage below economically significant values.

### Intercropping Promotes Plant Interactions

**Intercropping** means growing two or more crops in close proximity to each other during part or all of their life cycles) to promote interactions that improve soil and water quality via increased biodiversity and contribute to pest management (World Bank, 2008). Incorporating intercropping principles into an agricultural operation increases diversity and interaction between plants, arthropods, mammals, birds and microorganisms resulting in a more stable crop-ecosystem and a more efficient use of space, water, sunlight and nutrients (Figure 10.8).

Furthermore, soil health is benefited by increasing ground coverage with living vegetation, which reduces erosion,

FIGURE 10.7
Young larvae feed in and on the developing buds, often destroying them, which may stunt plants and delay or prevent flowering. Adults and older larvae feed on leaves and cause severe defoliation.

FIGURE 10.8
Intercropping alyssum with organic romaine lettuce for aphid control

and by increasing the quantity and diversity of root exudates, which enhance soil fauna. This collaborative type of crop management mimics nature and is subject to fewer pest outbreaks, improved nutrient cycling and crop nutrient uptake, and increased water infiltration and moisture retention. Soil quality, water quality and wildlife habitat all benefit

### Conservation Farming Practices Reduce Unnecessary Input Use

In modern agricultural practices, heavy machinery is used to prepare the seedbed, for planting, to control weeds, and to harvest the crop. The use of heavy equipment has many advantages in saving time and labor, but can cause compaction of soil and disruption of the natural soil biota. Much compaction is reversible and some is unavoidable with modern practices; however, serious compaction issues can occur with excessive passage of equipment during times when the soil has a high water content. The problem with soil compaction is that increased soil density limits root penetration depth and may inhibit proper plant growth.

Alternative practices generally encourage **minimal tillage** or **no tillage methods**. With proper planning, this can simultaneously limit compaction, protect soil biota, reduce costs (if performed correctly), promote water infiltration, and help to prevent topsoil erosion (Figure 10.9).

FIGURE 10.9
Farmers should consider no-till farming as the most important tool to prevent loss of soil moisture.

Tillage of fields does help to break up clods that were previously compacted, so best practices may vary at sites with different soil textures and composition. Another aspect of soil tillage is that it may lead to more rapid decomposition of organic matter due to greater soil aeration. Over large areas of farmland, this has the unintended consequence of releasing more carbon and nitrous oxides (greenhouse gases) into the atmosphere, thereby contributing to global warming effects. In no-till farming, carbon can actually become sequestered into the soil.

Thus, no-till farming may be advantageous to sustainability issues on the local scale and the global scale. No-till systems of conservation farming have proved a major success in Latin America and are being used in South Asia and Africa.

## Crop Rotation

Crop rotations are planned sequences of crops over time on the same field. Rotating crops provides productivity benefits by improving soil nutrient levels and breaking crop pest cycles. Farmers may also choose to rotate crops in order to reduce their production risk through diversification or to manage scarce resources, such as labor, during planting and harvesting timing. This strategy reduces the pesticide costs by naturally breaking the cycle of weeds, insects and diseases. Also, grass and legumes in a rotation protect water quality by preventing excess nutrients or chemicals from entering water supplies.

### TABLE 10.4:

| BOX 2. AN ALTERNATIVE TO SPRAYING: BOLLWORM CONTROL IN SHANDONG |
| --- |
| Farmers in Shandong (China) have been using innovative methods to control bollworm infestation in cotton when this insect became resistant to most pesticides. Among the control measures implemented were:<br>1. The use of pest resistant cultivars and interplanting of cotton with wheat or maize.<br>2. Use of lamps and poplar twigs to trap and kill adults to lessen the number of adults.<br>3. If pesticides were used, they were applied on parts of cotton plant's stem rather than by spraying the whole field (to protect natural enemies of the bollworm).<br>These and some additional biological control tools have proved to be effective in controlling insect populations and insect resistance, protecting surroundings and lowering costs. |

### Precision Agriculture Improves Productivity by Better Matching Management Practices to Local Crop and Soil Conditions

Relatively sophisticated technologies are used to vary input applications and production practices, according to seasonal conditions, soil and land characteristics, and production potential. However, with help from extension and other services, resource-poor farmers can also apply principles of precision agriculture for differential input application and management on dispersed small plots. Appropriate technologies suitable for use by small-scale farmers include simple color charts to guide decisions on fertilizer application and laser leveling of fields for irrigation.

## The Future of the Sustainable Agriculture Concept

Many in the agricultural community have adopted the sense of urgency and direction pointed to by the sustainable agriculture concept. Lack of sharp definition has not lessened its authenticity. Sustainability has become an integral component of many government, commercial, and non-profit agriculture research efforts, and it is beginning to be woven into agricultural policy. Increasing numbers of farmers and ranchers have embarked on their own paths to sustainability, incorporating integrated and innovative approaches into their own enterprises.

# 10.6 Resources

## Summary

In agriculture and horticulture, soil generally refers to the medium for plant growth, typically material within the upper meter or two. Soil plays a key role in plant growth. Beneficial aspects to plants include providing physical support, heat, water, nutrients, and oxygen. Heat, light, and oxygen are also obtained by the atmosphere, but the roots of many plants also require oxygen. The prevailing agricultural system has delivered tremendous gains in productivity and efficiency. Food production worldwide has risen in the past 50 years. On the other hand, agriculture profoundly affects many ecological systems. Negative effects of current practices include ecological concerns, economic and social concerns and human health concerns. Pesticides from every chemical class have been detected in groundwater and are commonly found in groundwater beneath agricultural areas. Despite impressive production gains, excessive use of pesticides has proven to be ecologically unsound, leading to the destruction of natural enemies, the increase of pest resistance pest resurgence and outbreaks of secondary pests. These consequences have often resulted in higher production costs and lost markets due to undesirable pesticide residue levels, as well as environmental and human health costs. Alternative and sustainable practices in farming and land use include organic agriculture, integrated pest management and biological control.

## Review Questions

1. What is the importance of soil to our society today?
2. Explain some negative impacts of conventional agriculture.
3. Explain the three characteristics of POPs that make them difficult to eradicate from the environment.
4. Explain the grasshopper effect.
5. Define terms pest and pesticide.
6. Explain the advantages of IPM approach.

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# CHAPTER 11 Conservation and Biodiversity

## Chapter Outline



FIGURE 11.1
Habitat destruction through deforestation, especially of tropical rainforests as seen in this satellite view of Amazon rainforests in Brazil, is a major cause of the current decline in biodiversity. (credit: modification of work by Jesse Allen and Robert Simmon, NASA Earth Observatory)

## Learning Outcomes

After studying this chapter, you should be able to :

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

# 11.1 Importance of Biodiversity

FIGURE 11.2
This tropical lowland rainforest in Madagascar is an example of a high biodiversity habitat. This particular location is protected within a national forest, yet only 10 percent of the original coastal lowland forest remains, and research suggests half the original biodiversity has been lost. (credit: Frank Vassen)

Biodiversity is a broad term for biological variety, and it can be measured at a number of organizational levels. Traditionally, ecologists have measured biodiversity by taking into account both the number of species and the number of individuals in each of those species. However, biologists are using measures of biodiversity at several levels of biological organization (including genes, populations, and ecosystems) to help focus efforts to preserve the biologically and technologically important elements of biodiversity.

When biodiversity loss through extinction is thought of as the loss of the passenger pigeon, the dodo, or, even, the woolly mammoth there seems to be no reason to care about it because these events happened long ago. How is the loss practically important for the welfare of the human species? Would these species have made our lives any better?

From the perspective of evolution and ecology, the loss of a particular individual species, with some exceptions, may seem unimportant, but the current accelerated extinction rate means the loss of tens of thousands of species within our lifetimes. Much of this loss is occurring in tropical rainforests like the one pictured in image above, which are especially high-diversity ecosystems that are being cleared for timber and agriculture. This is likely to have dramatic effects on human welfare through the collapse of ecosystems and in added costs to maintain food production, clean air and water, and improve human health.

Biologists recognize that human populations are embedded in ecosystems and are dependent on them, just as is every other species on the planet. Agriculture began after early hunter-gatherer societies first settled in one place and heavily modified their immediate environment: the ecosystem in which they existed. This cultural transition has made it difficult for humans to recognize their dependence on living things other than crops and domesticated animals on the planet. Today our technology smoothes out the extremes of existence and allows many of us to live longer, more comfortable lives, but ultimately the human species cannot exist without its surrounding ecosystems. Our ecosystems provide our food. This includes living plants that grow in soil ecosystems and the animals that eat these plants (or other animals) as well as photosynthetic organisms in the oceans and the other organisms that eat them. Our ecosystems have provided and will provide many of the medications that maintain our health, which are commonly made from compounds found in living organisms. Ecosystems provide our clean water, which is held in lake and river ecosystems or passes through terrestrial ecosystems on its way into groundwater.

## Types of Biodiversity

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

### Genetic and Chemical Biodiversity

Genetic diversity is one alternate concept of biodiversity. **Genetic diversity** (or variation) is the raw material for adaptation in a species. A species' future potential for adaptation depends on the genetic diversity held in the genomes of the individuals in populations that make up the species. The same is true for higher taxonomic categories. A genus with very different types of species will have more genetic diversity than a genus with species that look alike and have similar ecologies. The genus with the greatest potential for subsequent evolution is the most genetically diverse one.

Most genes code for proteins, which in turn carry out the metabolic processes that keep organisms alive and reproducing. Genetic diversity can also be conceived of as **chemical diversity** in that species with different genetic makeups produce different assortments of chemicals in their cells (proteins as well as the products and byproducts of metabolism). This chemical diversity is important for humans because of the potential uses for these chemicals, such as medications. For example, the drug eptifibatide is derived from rattlesnake venom and is used to prevent heart attacks in individuals with certain heart conditions.

At present, it is far cheaper to discover compounds made by an organism than to imagine them and then synthesize them in a laboratory. Chemical diversity is one way to measure diversity that is important to human health and welfare. Through selective breeding, humans have domesticated animals, plants, and fungi, but even this diversity is suffering losses because of market forces and increasing globalism in human agriculture and migration. For example, international seed companies produce only a very few varieties of a given crop and provide incentives around the world for farmers to buy these few varieties while abandoning their traditional varieties, which are far more diverse. The human population depends on crop diversity directly as a stable food source and its decline is troubling to biologists and agricultural scientists.

### Ecosystems Diversity

It is also useful to define **ecosystem diversity**: the number of different ecosystems on Earth or in a geographical area. Whole ecosystems can disappear even if some of the species might survive by adapting to other ecosystems. The loss of an ecosystem means the loss of the interactions between species, the loss of unique features of coadaptation, and the loss of biological productivity that an ecosystem is able to create. An example of a largely extinct ecosystem in North America is the prairie ecosystem (Figure 11.3). Prairies once spanned central North America from the boreal forest in northern Canada down into Mexico. They are now all but gone, replaced by crop fields, pasture lands, and suburban sprawl. Many of the species survive, but the hugely productive ecosystem that was responsible for creating our most productive agricultural soils is now gone. As a consequence, their soils are now being depleted unless they are maintained artificially at greater expense. The decline in soil productivity occurs because the interactions in the original ecosystem have been lost; this was a far more important loss than the relatively few species that were driven extinct when the prairie ecosystem was destroyed.

FIGURE 11.3

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

## Current Species Diversity

Despite considerable effort, knowledge of the species that inhabit the planet is limited. A recent estimate suggests that the eukaryote species for which science has names, about 1.5 million species, account for less than 20 percent of the total number of eukaryote species present on the planet (8.7 million species, by one estimate). Estimates of numbers of prokaryotic species are largely guesses, but biologists agree that science has only just begun to catalog their diversity. Even with what is known, there is no centralized repository of names or samples of the described species; therefore, there is no way to be sure that the 1.5 million descriptions is an accurate number. It is a best guess based on the opinions of experts on different taxonomic groups. Given that Earth is losing species at an accelerating pace, science knows little about what is being lost. Table below presents recent estimates of biodiversity in different groups.

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

Naming and counting species may seem an unimportant pursuit given the other needs of humanity, but it is not simply an accounting. Describing species is a complex process by which biologists determine an organism's unique characteristics and whether or not that organism belongs to any other described species. It allows biologists to find and recognize the species after the initial discovery to follow up on questions about its biology. That subsequent

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

FIGURE 11.4
This table shows the estimated number of species by taxonomic group—including both described (named and studied) and predicted (yet to be named) species.

research will produce the discoveries that make the species valuable to humans and to our ecosystems. Without a name and description, a species cannot be studied in depth and in a coordinated way by multiple scientists.

## Patterns of Biodiversity

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

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

One of the oldest observed patterns in ecology is that biodiversity in almost every taxonomic group of organism increases as latitude declines. In other words, biodiversity increases closer to the equator (Figure 11.4).

It is not yet clear why biodiversity increases closer to the equator, but hypotheses include the greater age of the

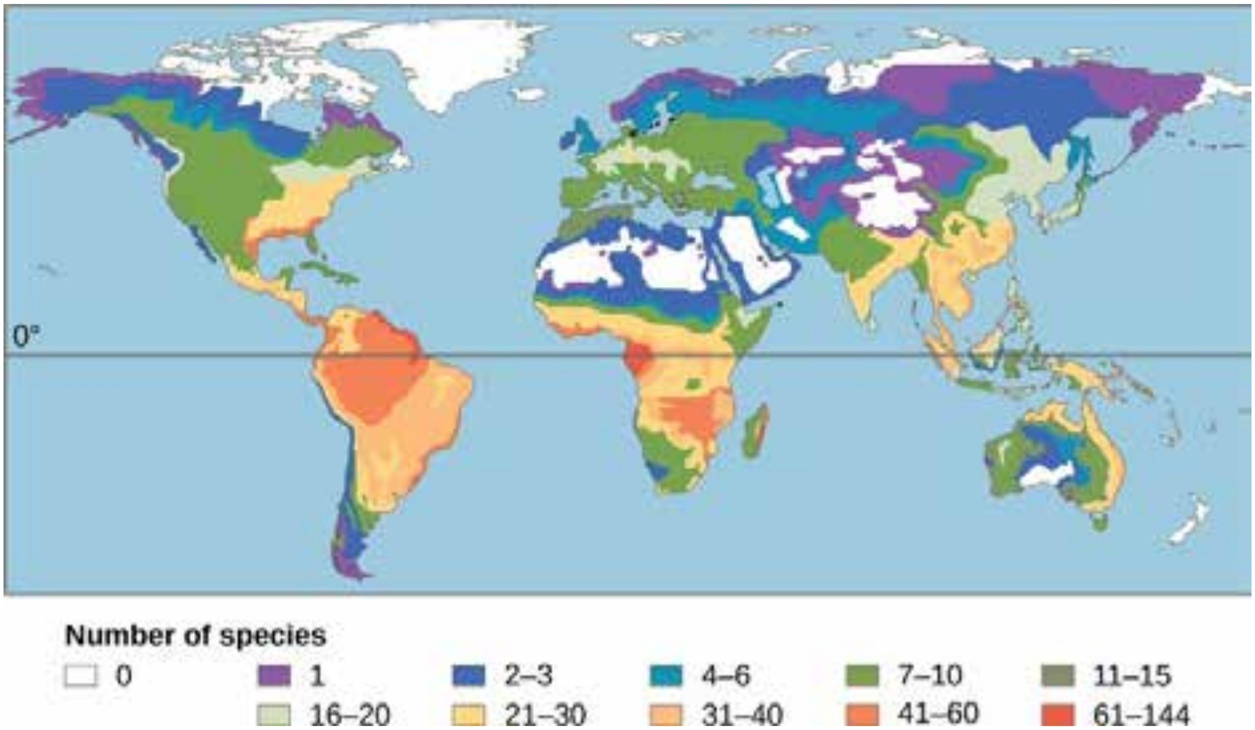


FIGURE 11.5
This map illustrates the number of amphibian species across the globe and shows the trend toward higher biodiversity at lower latitudes. A similar pattern is observed for most taxonomic groups.

ecosystems in the tropics versus temperate regions, which were largely devoid of life or drastically impoverished during the last ice age. The greater age provides more time for speciation. Another possible explanation is the greater energy the tropics receive from the sun versus the lesser energy input in temperate and polar regions. But scientists have not been able to explain how greater energy input could translate into more species. The complexity of tropical ecosystems may promote speciation by increasing the **habitat heterogeneity**, or number of ecological niches, in the tropics relative to higher latitudes. The greater heterogeneity provides more opportunities for coevolution, specialization, and perhaps greater selection pressures leading to population differentiation. However, this hypothesis suffers from some circularity—ecosystems with more species encourage speciation, but how did they get more species to begin with? The tropics have been perceived as being more stable than temperate regions, which have a pronounced climate and day-length seasonality. The tropics have their own forms of seasonality, such as rainfall, but they are generally assumed to be more stable environments and this stability might promote speciation.

Regardless of the mechanisms, it is certainly true that biodiversity is greatest in the tropics. The number of endemic species is higher in the tropics. The tropics also contain more biodiversity hotspots. At the same time, our knowledge of the species living in the tropics is lowest and because of recent, heavy human activity the potential for biodiversity loss is greatest.

## Importance of Biodiversity

Loss of biodiversity eventually threatens other species we do not impact directly because of their interconnectedness; as species disappear from an ecosystem other species are threatened by the changes in available resources.

Biodiversity is important to the survival and welfare of human populations because it has impacts on our health and our ability to feed ourselves through agriculture and harvesting populations of wild animals.

### Human Health

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

Modern pharmaceutical science also recognizes the importance of these plant compounds. Examples of significant medicines derived from plant compounds include aspirin, codeine, digoxin, atropine, and vincristine (Figure 11.5). Many medications were once derived from plant extracts but are now synthesized. It is estimated that, at one time, 25 percent of modern drugs contained at least one plant extract. That number has probably decreased to about 10 percent as natural plant ingredients are replaced by synthetic versions of the plant compounds. Antibiotics, which are responsible for extraordinary improvements in health and lifespans in developed countries, are compounds largely derived from fungi and bacteria.

FIGURE 11.6

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

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

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

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

### Agricultural

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

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

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

Since the 1920s, government agriculture departments have maintained seed banks of crop varieties as a way to maintain crop diversity. This system has flaws because over time seed varieties are lost through accidents and there is no way to replace them. In 2008, the Svalbard Global seed Vault, located on Spitsbergen island, Norway, (Figure 11.6) began storing seeds from around the world as a backup system to the regional seed banks. If a regional seed bank stores varieties in Svalbard, losses can be replaced from Svalbard should something happen to the regional seeds. The Svalbard seed vault is deep into the rock of the arctic island. Conditions within the vault are maintained at ideal temperature and humidity for seed survival, but the deep underground location of the vault in the arctic means that failure of the vault's systems will not compromise the climatic conditions inside the vault.

**ART CONNECTION**

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

The Svalbard seed vault is located on Spitsbergen island in Norway, which has an arctic climate. Why might an arctic climate be good for seed storage?

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

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

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

## Wild Food Sources

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

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

# 11.2 Threats to Biodiversity

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

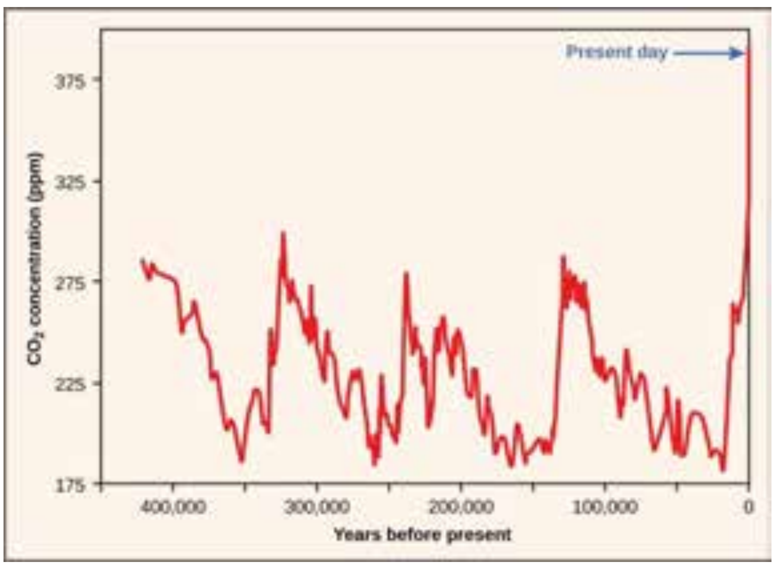


FIGURE 11.7
Atmospheric carbon dioxide levels fluctuate in a cyclical manner. However, the burning of fossil fuels in recent history has caused a dramatic increase in the levels of carbon dioxide in the Earth's atmosphere, which have now reached levels never before seen on Earth. Scientists predict that the addition of this "green- house gas" to the atmosphere is resulting in climate change that will significantly impact biodiversity in the coming century.

### Habitat Loss

Humans rely on technology to modify their environment and replace certain functions that were once performed by the natural ecosystem. Other species cannot do this. Elimination of their habitat—whether it is a forest, coral reef, grassland, or flowing river—will kill the individuals in the species. Remove the entire habitat within the range of a species and, unless they are one of the few species that do well in human-built environments, the species will become extinct. Human destruction of habitats (habitats generally refer to the part of the ecosystem required by a particular species) accelerated in the latter half of the twentieth century. Consider the exceptional biodiversity of Sumatra: it is home to one species of orangutan, a species of critically endangered elephant, and the Sumatran tiger, but half of Sumatra's forest is now gone. The neighboring island of Borneo, home to the other species of orangutan, has lost a similar area of forest. Forest loss continues in protected areas of Borneo. The orangutan in Borneo is listed as endangered by the International Union for Conservation of Nature (IUCN), but it is simply the most visible of thousands of species that will not survive the disappearance of the forests of Borneo. The forests are removed for timber and to plant palm oil plantations (Figure below). Palm oil is used in many products including food products, cosmetics, and biodiesel in Europe. A 5-year estimate of global forest cover loss for the years from 2000 to 2005 was 3.1 percent. Much loss (2.4 percent) occurred in the humid tropics where forest loss is primarily from timber extraction. These losses certainly also represent the extinction of species unique to those areas.

FIGURE 11.8
An oil palm plantation in Sabah province Borneo, Malaysia, replaces native forest habitat that a variety of species depended on to live. (credit: Lian Pin Koh)

**BIOLOGY IN ACTION**

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

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

Habitat destruction can affect ecosystems other than forests. Rivers and streams are important ecosystems and are frequently the target of habitat modification through building and from damming or water removal. Damming of rivers affects flows and access to all parts of a river. Altering a flow regime can reduce or eliminate populations that are adapted to seasonal changes in flow. For example, an estimated 91 percent of river lengths in the United

States have been modified with damming or bank modifications. Many fish species in the United States, especially rare species or species with restricted distributions, have seen declines caused by river damming and habitat loss. Research has confirmed that species of amphibians that must carry out parts of their life cycles in both aquatic and terrestrial habitats are at greater risk of population declines and extinction because of the increased likelihood that one of their habitats or access between them will be lost. This is of particular concern because amphibians have been declining in numbers and going extinct more rapidly than many other groups for a variety of possible reasons.

### Overharvesting

Overharvesting is a serious threat to many species, but particularly to aquatic species. There are many examples of regulated fisheries (including hunting of marine mammals and harvesting of crustaceans and other species) monitored by fisheries scientists that have nevertheless collapsed. The western Atlantic cod fishery is the most spectacular recent collapse. While it was a hugely productive fishery for 400 years, the introduction of modern factory trawlers in the 1980s and the pressure on the fishery led to it becoming unsustainable. The causes of fishery collapse are both economic and political in nature. Most fisheries are managed as a common resource, available to anyone willing to fish, even when the fishing territory lies within a country's territorial waters. Common resources are subject to an economic pressure known as the tragedy of the commons, in which fishers have little motivation to exercise restraint in harvesting a fishery when they do not own the fishery. The general outcome of harvests of resources held in common is their overexploitation. While large fisheries are regulated to attempt to avoid this pressure, it still exists in the background. This overexploitation is exacerbated when access to the fishery is open and unregulated and when technology gives fishers the ability to overfish. In a few fisheries, the biological growth of the resource is less than the potential growth of the profits made from fishing if that time and money were invested elsewhere. In these cases—whales are an example—economic forces will drive toward fishing the population to extinction.

**CONCEPT IN ACTION**

Explore a U.S. Fish & Wildlife Service interactive map of critical habitat for endangered and threatened species in

For the most part, fishery extinction is not equivalent to biological extinction—the last fish of a species is rarely fished out of the ocean. But there are some instances in which true extinction is a possibility. Whales have slow-growing populations and are at risk of complete extinction through hunting. Also, there are some species of sharks with restricted distributions that are at risk of extinction. The groupers are another population of generally slow-growing fishes that, in the Caribbean, includes a number of species that are at risk of extinction from overfishing.

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

**CONCEPT IN ACTION**

View a brief video discussing the role of marine ecosystems in supporting human welfare and the decline of ocean

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

### Exotic Species

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

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

**CONCEPT IN ACTION**

Explore this interactive global database of exotic or invasive species.

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

FIGURE 11.9

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

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

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

FIGURE 11.10

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

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

FIGURE 11.11

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

### Climate Change

Climate change, and specifically the anthropogenic warming trend presently underway, is recognized as a major extinction threat, particularly when combined with other threats such as habitat loss. Anthropogenic warming of the planet has been observed and is hypothesized to continue due to past and continuing emission of greenhouse gases, primarily carbon dioxide and methane, into the atmosphere caused by the burning of fossil fuels and deforestation. These gases decrease the degree to which Earth is able to radiate heat energy created by the sunlight that enters the atmosphere. The changes in climate and energy balance caused by increasing greenhouse gases are complex and our understanding of them depends on predictions generated from detailed computer models. Scientists generally agree the present warming trend is caused by humans and some of the likely effects include dramatic and dangerous climate changes in the coming decades. However, there is still debate and a lack of understanding about specific outcomes. Scientists disagree about the likely magnitude of the effects on extinction rates, with estimates ranging from 15 to 40 percent of species committed to extinction by 2050. Scientists do agree that climate change will alter regional climates, including rainfall and snowfall patterns, making habitats less hospitable to the species living in them. The warming trend will shift colder climates toward the north and south poles, forcing species to move with their adapted climate norms, but also to face habitat gaps along the way. The shifting ranges will impose new competitive regimes on species as they find themselves in contact with other species not present in their historic range. One such unexpected species contact is between polar bears and grizzly bears. Previously, these two species had separate ranges. Now, their ranges are overlapping and there are documented cases of these two species mating and producing viable offspring. Changing climates also throw off the delicate timing adaptations that species have to seasonal food resources and breeding times. Scientists have already documented many contemporary mismatches to shifts in resource availability and timing.

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

Climate gradients will also move up mountains, eventually crowding species higher in altitude and eliminating the habitat for those species adapted to the highest elevations. Some climates will completely disappear. The rate of warming appears to be accelerated in the arctic, which is recognized as a serious threat to polar bear populations that require sea ice to hunt seals during the winter months: seals are the only source of protein available to polar bears. A trend to decreasing sea ice coverage has occurred since observations began in the mid-twentieth century. The rate of decline observed in recent years is far greater than previously predicted by climate models (11.12 Figure below).


FIGURE 11.12

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

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

# 11.3 Preserving Biodiversity

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

## Change in Biodiversity through Time

The number of species on the planet, or in any geographical area, is the result of an equilibrium of two evolutionary processes that are ongoing: speciation and extinction. Both are natural "birth" and "death" processes of macroevolution. When speciation rates begin to outstrip extinction rates, the number of species will increase; likewise, the reverse is true when extinction rates begin to overtake speciation rates. Throughout the history of life on Earth, as reflected in the fossil record, these two processes have fluctuated to a greater or lesser extent, sometimes leading to dramatic changes in the number of species on the planet as reflected in the fossil record (Figure 11.13).

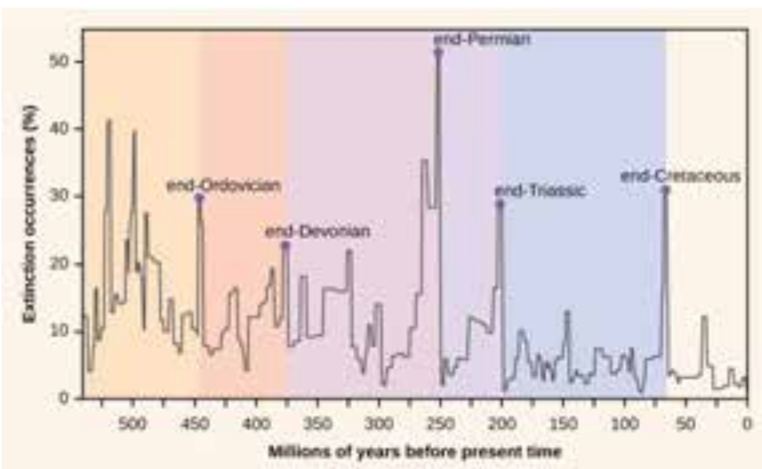


FIGURE 11.13

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

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

## Recent and Current Extinction Rates

A sixth, or Holocene, mass extinction has mostly to do with the activities of *Homo sapiens*. There are numerous recent extinctions of individual species that are recorded in human writings. Most of these are coincident with the expansion of the European colonies since the 1500s.

One of the earlier and popularly known examples is the dodo bird. The dodo bird lived in the forests of Mauritius, an island in the Indian Ocean. The dodo bird became extinct around 1662. It was hunted for its meat by sailors and was easy prey because the dodo, which did not evolve with humans, would approach people without fear. Introduced pigs, rats, and dogs brought to the island by European ships also killed dodo young and eggs (see11.14 Figure below).

FIGURE 11.14

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

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

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

### Estimates of Present-day Extinction Rates

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

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

A second approach to estimating present-time extinction rates is to correlate species loss with habitat loss, and it is based on measuring forest-area loss and understanding species–area relationships. The species-area relationship is the rate at which new species are seen when the area surveyed is increased (Figure 11.15). Likewise, if the habitat area is reduced, the number of species seen will also decline. This kind of relationship is also seen in the relationship between an island's area and the number of species present on the island: as one increases, so does the other, though not in a straight line. Estimates of extinction rates based on habitat loss and species–area relationships have suggested that with about 90 percent of habitat loss an expected 50 percent of species would become extinct. Figure 11.16 shows that reducing forest area from 100 $km^2$ to 10 $km^2$, a decline of 90 percent, reduces the number of species by about 50 percent. Species–area estimates have led to estimates of present-day species extinction rates of about 1000 E/MSY and higher. In general, actual observations do not show this amount of loss and one explanation put forward is that there is a delay in extinction. According to this explanation, it takes some time for species to fully suffer the effects of habitat loss and they linger on for some time after their habitat is destroyed, but eventually they will become extinct. Recent work has also called into question the applicability of the species-area relationship when estimating the loss of species. This work argues that the species–area relationship leads to an overestimate of extinction rates. Using an alternate method would bring estimates down to around 500 E/MSY in the coming century. Note that this value is still 500 times the background rate.

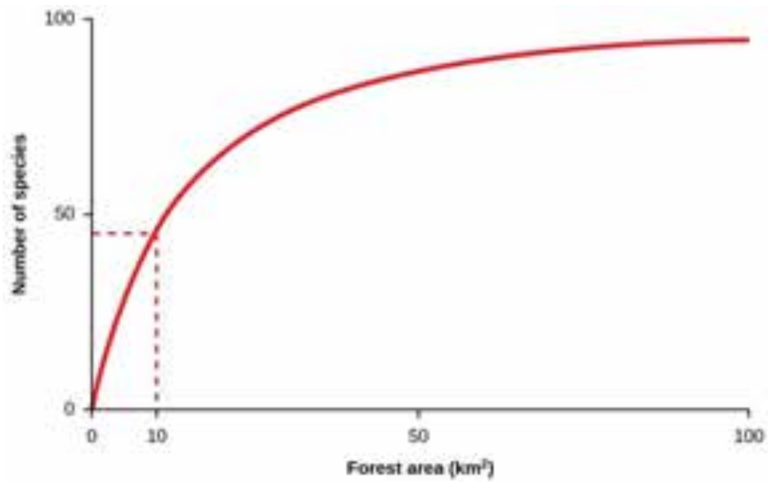


FIGURE 11.15

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

**Conservation of Biodiversity**

The threats to biodiversity at the genetic, species, and ecosystem levels have been recognized for some time. In the United States, the first national park with land set aside to remain in a wilderness state was Yellowstone Park in 1890. However, attempts to preserve nature for various reasons have occurred for centuries. Today, the main efforts to preserve biodiversity involve legislative approaches to regulate human and corporate behavior, setting aside protected areas, and habitat restoration.

*Changing Human Behavior*

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

Within many countries there are laws that protect endangered species and that regulate hunting and fishing. In the United States, the Endangered Species Act was enacted in 1973. When an at-risk species is listed by the Act, the U.S. Fish & Wildlife Service is required by law to develop a management plan to protect the species and bring it back to sustainable numbers. The Act, and others like it in other countries, is a useful tool, but it suffers because it is often difficult to get a species listed, or to get an effective management plan in place once a species is listed. Additionally, species may be controversially taken off the list without necessarily having had a change in their situation. More fundamentally, the approach to protecting individual species rather than entire ecosystems (although the management plans commonly involve protection of the individual species' habitat) is both inefficient and focuses efforts on a few highly visible and often charismatic species, perhaps at the expense of other species that go unprotected.

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

Global warming is expected to be a major driver of biodiversity loss. Many governments are concerned about the effects of anthropogenic global warming, primarily on their economies and food resources. Since greenhouse gas emissions do not respect national boundaries, the effort to curb them is an international one. The international response to global warming has been mixed. The Kyoto Protocol, an international agreement that came out of the United Nations Framework Convention on Climate Change that committed countries to reducing greenhouse gas emissions by 2012, was ratified by some countries, but spurned by others. Two countries that were especially important in terms of their potential impact that did not ratify the Kyoto protocol were the United States and China. Some goals for reduction in greenhouse gasses were met and exceeded by individual countries, but, worldwide, the effort to limit greenhouse gas production is not succeeding. The intended replacement for the Kyoto Protocol has not materialized because governments cannot agree on timelines and benchmarks. Meanwhile, the resulting costs to human societies and biodiversity predicted by a majority of climate scientists will be high.

As already mentioned, the non-profit, non-governmental sector plays a large role in conservation effort both in North America and around the world. The approaches range from species-specific organizations to the broadly focused IUCN and Trade Records Analysis of Flora and Fauna in Commerce (TRAFFIC). The Nature Conservancy takes a novel approach. It purchases land and protects it in an attempt to set up preserves for ecosystems. Ultimately, human behavior will change when human values change. At present, the growing urbanization of the human population is a force that mitigates against valuing biodiversity, because many people no longer come in contact with natural environments and the species that inhabit them.

*Conservation in Preserves*

Establishment of wildlife and ecosystem preserves is one of the key tools in conservation efforts (Figure 11.16). A preserve is an area of land set aside with varying degrees of protection for the organisms that exist within the boundaries of the preserve. Preserves can be effective for protecting both species and ecosystems, but they have some serious drawbacks.

FIGURE 11.16

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

A simple measure of success in setting aside preserves for biodiversity protection is to set a target percentage of land or marine habitat to protect. However, a more detailed preserve design and choice of location is usually necessary because of the way protected lands are allocated and how biodiversity is distributed: protected lands tend to contain less economically valuable resources rather than being set aside specifically for the species or ecosystems at risk. In

2003, the IUCN World Parks Congress estimated that 11.5 percent of Earth's land surface was covered by preserves of various kinds. This area is greater than previous goals; however, it only represents 9 out of 14 recognized major biomes and research has shown that 12 percent of all species live outside preserves; these percentages are much higher when threatened species are considered and when only high quality preserves are considered. For example, high quality preserves include only about 50 percent of threatened amphibian species. The conclusion must be that either the percentage of area protected must be increased, the percentage of high quality preserves must be increased, or preserves must be targeted with greater attention to biodiversity protection. Researchers argue that more attention to the latter solution is required.

A biodiversity hotspot is a conservation concept developed by Norman Myers in 1988. Hotspots are geographical areas that contain high numbers of endemic species. The purpose of the concept was to identify important locations on the planet for conservation efforts, a kind of conservation triage. By protecting hotspots, governments are able to protect a larger number of species. The original criteria for a hotspot included the presence of 1500 or more species of endemic plants and 70 percent of the area disturbed by human activity. There are now 34 biodiversity hotspots (Figure 11.17) that contain large numbers of endemic species, which include half of Earth's endemic plants.

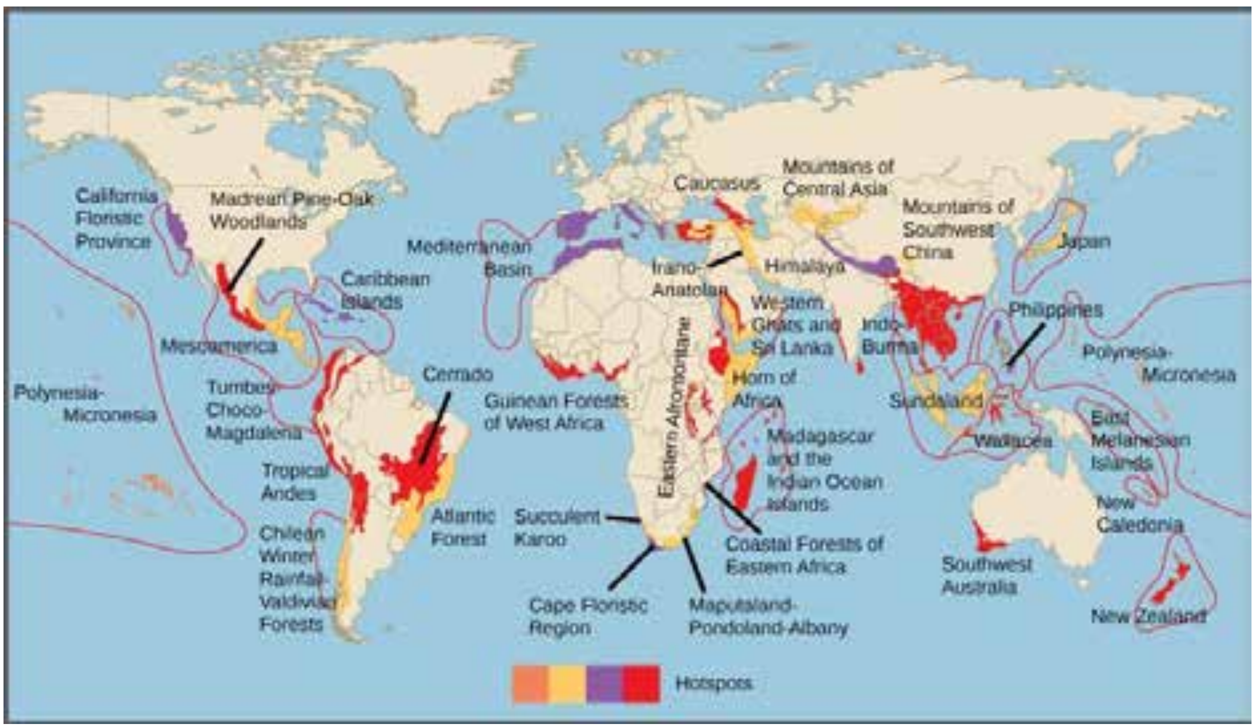


FIGURE 11.17

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

There has been extensive research into optimal preserve designs for maintaining biodiversity. The fundamental principles behind much of the research have come from the seminal theoretical work of Robert H. MacArthur and Edward O. Wilson published in 1967 on island biogeography. This work sought to understand the factors affecting biodiversity on islands. Conservation preserves can be seen as "islands" of habitat within "an ocean" of non-habitat. In general, large preserves are better because they support more species, including species with large home ranges; they have more core area of optimal habitat for individual species; they have more niches to support more species;

and they attract more species because they can be found and reached more easily.

Preserves perform better when there are partially protected buffer zones around them of suboptimal habitat. The buffer allows organisms to exit the boundaries of the preserve without immediate negative consequences from hunting or lack of resources. One large preserve is better than the same area of several smaller preserves because there is more core habitat unaffected by less hospitable ecosystems outside the preserve boundary. For this same reason, preserves in the shape of a square or circle will be better than a preserve with many thin "arms." If preserves must be smaller, then providing wildlife corridors between them so that species and their genes can move between the preserves; for example, preserves along rivers and streams will make the smaller preserves behave more like a large one. All of these factors are taken into consideration when planning the nature of a preserve before the land is set aside.

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

Some of the limitations on preserves as conservation tools are evident from the discussion of preserve design. Political and economic pressures typically make preserves smaller, never larger, so setting aside areas that are large enough is difficult. Enforcement of protections is also a significant issue in countries without the resources or political will to prevent poaching and illegal resource extraction.

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

Finally, an argument can be made that conservation preserves reinforce the cultural perception that humans are separate from nature, can exist outside of it, and can only operate in ways that do damage to biodiversity. Creating preserves reduces the pressure on human activities outside the preserves to be sustainable and non-damaging to biodiversity. Ultimately, the political, economic, and human demographic pressures will degrade and reduce the size of conservation preserves if the activities outside them are not altered to be less damaging to biodiversity.

*Habitat Restoration*

Habitat restoration holds considerable promise as a mechanism for maintaining or restoring biodiversity. Of course once a species has become extinct, its restoration is impossible. However, restoration can improve the biodiversity of degraded ecosystems. Reintroducing wolves, a top predator, to Yellowstone National Park in 1995 led to dramatic changes in the ecosystem that increased biodiversity. The wolves (Figure 11.18) function to suppress elk and coyote populations and provide more abundant resources to the guild of carrion eaters. Reducing elk populations has allowed revegetation of riparian (the areas along the banks of a stream or river) areas, which has increased the diversity of species in that habitat. Suppression of coyotes has increased the species previously suppressed by this predator. The number of species of carrion eaters has increased because of the predatory activities of the wolves. In this habitat, the wolf is a keystone species, meaning a species that is instrumental in maintaining diversity within an ecosystem. Removing a keystone species from an ecological community causes a collapse in diversity. The results from the Yellowstone experiment suggest that restoring a keystone species effectively can have the effect of restoring biodiversity in the community. Ecologists have argued for the identification of keystone species where possible and for focusing protection efforts on these species. It makes sense to return the keystone species to the ecosystems where they have been removed.

Other large-scale restoration experiments underway involve dam removal. In the United States, since the mid-1980s, many aging dams are being considered for removal rather than replacement because of shifting beliefs about the

FIGURE 11.18

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

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

### The Role of Zoos and Captive Breeding

Zoos have sought to play a role in conservation efforts both through captive breeding programs and education (Figure 11.19). The transformation of the missions of zoos from collection and exhibition facilities to organizations that are dedicated to conservation is ongoing. In general, it has been recognized that, except in some specific targeted cases, captive breeding programs for endangered species are inefficient and often prone to failure when the species are reintroduced to the wild. Zoo facilities are far too limited to contemplate captive breeding programs for the numbers of species that are now at risk. Education, on the other hand, is a potential positive impact of zoos on conservation efforts, particularly given the global trend to urbanization and the consequent reduction in contacts between people and wildlife. A number of studies have been performed to look at the effectiveness of zoos on people's attitudes and actions regarding conservation; at present, the results tend to be mixed.

FIGURE 11.19

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

# 11.4 Resources

## Summary

Biodiversity exists at multiple levels of organization, and is measured in different ways depending on the goals of those taking the measurements. These include numbers of species, genetic diversity, chemical diversity, and ecosystem diversity. Humans use many compounds that were first discovered or derived from living organisms as medicines: secondary plant compounds, animal toxins, and antibiotics produced by bacteria and fungi. Ecosystems provide ecosystem services that support human agriculture: pollination, nutrient cycling, pest control, and soil development and maintenance. Loss of biodiversity threatens these ecosystem services and risks making food production more expensive or impossible. The core threats to biodiversity are human population growth and unsustainable resource use. Climate change is predicted to be a significant cause of extinction in the coming century. Exotic species have been the cause of a number of extinctions and are especially damaging to islands and lakes. International treaties such as CITES regulate the transportation of endangered species across international borders. In the United States, the Endangered Species Act protects listed species but is hampered by procedural difficulties and a focus on individual species. The Migratory Bird Act is an agreement between Canada and the United States to protect migratory birds. Presently, 11 percent of Earth's land surface is protected in some way. Habitat restoration has the potential to restore ecosystems to previous biodiversity levels before species become extinct. Examples of restoration include reintroduction of keystone species and removal of dams on rivers.

## Review Questions

- Describe two types of compounds from living things that are used as medications.
- Describe the mechanisms by which human population growth and resource use causes increased extinction rates.
- What extinction threats a frog living on a mountainside in Costa Rica might face?
- Describe two considerations in conservation preserve design.
- What happens to an ecosystem when a keystone species is removed?

# 11.5 References

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# CHAPTER 12 Air Pollution, Climate Change, and Ozone Depletion

## Chapter Outline



FIGURE 12.1

Traffic congestion is a daily reality of India's urban centers. Slow speeds and idling vehicles produce, per trip, 4 to 8 times more pollutants and consume more carbon footprint fuels, than free flowing traffic. This 2008 image shows traffic congestion in Delhi.

Nomad. (2008). Trafficjamdelhi. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Trafficjamdelhi.jpg

## Learning Outcomes

After studying this chapter, you should be able to:

- Identify sources of air pollution
- List common air pollutants
- Explain how the greenhouse effect causes the atmosphere to retain heat
- Explain how we know that humans are responsible for recent climate change
- List some effects of climate change
- Identify some climate change policies and adaptation measures

## 12.1 Atmospheric Pollution

Air pollution occurs in many forms but can generally be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere (University of California College Prep, 2012). Chemicals discharged into the air that have a direct impact on the environment are called **primary pollutants**. These primary pollutants sometimes react with other chemicals in the air to produce **secondary pollutants**.

Air pollution is typically separated into two categories: outdoor air pollution and **indoor** air **pollution**. Outdoor air pollution involves exposures that take place outside of the built environment. Examples include fine particles produced by the burning of coal, noxious gases such as sulfur dioxide, nitrogen oxides and carbon monoxide, ground-level ozone and tobacco smoke. Indoor air pollution involves exposures to particulates, carbon oxides, and other pollutants carried by indoor air or dust. Examples include gases, household products and chemicals, building materials (asbestos, formaldehyde, lead, etc.) outdoor indoor allergens (cockroach and mouse dropping, etc.), tobacco smoke, mold and pollen.

### Sources of Air Pollution

**Stationary and Area Sources.** A stationary source of air pollution refers to an emission source that does not move, also known as a point source. Stationary sources include factories, power plants, dry cleaners and degreasing operations. The term area source is used to describe many small sources of air pollution located together whose individual emissions may be below thresholds of concern, but whose collective emissions can be significant. Residential wood burners are a good example of a small source, but when combined with many other small sources, they can contribute to local and regional air pollution levels. Area sources can also be thought of as non-point sources, such as construction of housing developments, dry lake beds, and landfills.

**Mobile Sources.** A mobile source of air pollution refers to a source that is capable of moving under its own power. In general, mobile sources imply "on-road" transportation, which includes vehicles such as cars, sport utility vehicles, and buses. In addition, there is also a "non-road" or "off-road" category that includes gas-powered lawn tools and mowers, farm and construction equipment, recreational vehicles, boats, planes, and trains.

**Agricultural Sources.** Agricultural operations, those that raise animals and grow crops, can generate emissions of gases and particulate matter. For example, animals confined to a barn or restricted area (rather than field grazing), produce large amounts of manure. Manure emits various gases, particularly ammonia into the air. This ammonia can be emitted from the animal houses, manure storage areas, or from the land after the manure is applied. In crop production, the misapplication of fertilizers, herbicides, and pesticides can potentially result in aerial drift of these materials and harm may be caused.

**Natural Sources.** Although industrialization and the use of motor vehicles are overwhelmingly the most significant contributors to air pollution, there are important natural sources of "pollution" as well. Wildland fires, dust storms, and volcanic activity also contribute gases and particulates to our atmosphere.

Unlike the above mentioned sources of air pollution, natural "air pollution" is not caused by people or their activities. An erupting volcano emits particulate matter and gases; forest and prairie fires can emit large quantities of "pollutants"; plants and trees naturally emit VOCs which are oxidized and form aerosols that can cause a natural blue haze; and dust storms can create large amounts of particulate matter. Wild animals in their natural habitat are also considered natural sources of "pollution".

### Six Common Air Pollutants

The commonly found air pollutants (also known as " **criteria pollutants**") are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants can harm health and the environment, and cause property damage. Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. The U.S. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels. The set of limits based on human health is called **primary standards**. Another set of limits intended to prevent environmental and property damage is called **secondary standards**.

Ground level or "bad" **ozone** is not emitted directly into the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground level ozone can also have harmful effects on sensitive vegetation and ecosystems.

**Particulate matter**, also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects.

**Carbon monoxide** (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death.

**Nitrogen dioxide** ($NO_2$) is one of a group of highly reactive gasses known as "oxides of nitrogen," or nitrogen oxides (NOx). Other nitrogen oxides include nitrous acid and nitric acid. EPA's National Ambient Air Quality Standard uses $NO_2$ as the indicator for the larger group of nitrogen oxides. NO2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO2 is linked with a number of adverse effects on the respiratory system.

**Sulfur dioxide** ($SO_2$) is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of $SO_2$ emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of $SO_2$ emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. $SO_2$ is linked with a number of adverse effects on the respiratory system.

**Lead** is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in on-road motor vehicles (such as cars and trucks) and industrial sources. As a result of regulatory efforts in the U.S. to remove lead from on-road motor vehicle gasoline, emissions of lead from the transportation sector dramatically declined by 95 percent between 1980 and 1999, and levels of lead in the air decreased by 94 percent between 1980 and 1999. Today, the highest levels of lead in air are usually found near lead smelters. The major sources of lead emissions to the air today are ore and metals processing and piston-engine aircraft operating on leaded aviation gasoline.

### Indoor Air Pollution (Major concerns in developed countries)

Most people spend approximately 90 percent of their time indoors. However, the indoor air we breathe in homes and other buildings can be more polluted than outdoor air and can increase the risk of illness. There are many sources of indoor air pollution in homes. They include biological contaminants such as bacteria, molds and pollen, burning of fuels and environmental tobacco smoke (see Figure 12.1), building materials and furnishings, household products, central heating and cooling systems, and outdoor sources. Outdoor air pollution can enter buildings and become a source of indoor air pollution.

*Sick building syndrome* is a term used to describe situations in which building occupants have health symptoms that are associated only with spending time in that building. Causes of sick building syndrome are believed to include inadequate ventilation, indoor air pollution, and biological contaminants.

Usually indoor air quality problems only cause discomfort. Most people feel better as soon as they remove the source of the pollution. Making sure that your building is well-ventilated and getting rid of pollutants can improve the quality of your indoor air.

### TABLE 12.1:

| **Secondhand Smoke (Environmental Tobacco Smoke)** |
|---|
| Secondhand smoke is the combination of smoke that comes from a cigarette and smoke breathed out by a smoker. When a non-smoker is around someone smoking, they breathe in secondhand smoke.<br>Secondhand smoke is dangerous to anyone who breathes it in. There is no safe amount of secondhand smoke. It contains over 7,000 harmful chemicals, at least 250 of which are known to damage human health. It can also stay in the air for several hours after somebody smokes. Even breathing secondhand smoke for a short amount of time can hurt your body.<br>Over time, secondhand smoke can cause serious health issues in non-smokers. The only way to fully protect non-smokers from the dangers of secondhand smoke is to not allow smoking indoors. Separating smokers from nonsmokers (like "no smoking" sections in restaurants), cleaning the air, and airing out buildings does not completely get rid of secondhand smoke. |

Smokefree. (2019). Secondhand smoke. Retrieved from https://smokefree.gov/quit-smoking/why-you-should-quit/secondhand-smoke

## 12.2 Ozone Depletion

The ozone depletion process begins when CFCs and other ozone-depletingsubstances (ODS) are emitted into the atmosphere (CK12, 2015). Winds efficiently mix the troposphere and evenly distribute the gases. CFCs are extremely stable, and they do not dissolve in rain. After a period of several years, ODS molecules reach the stratosphere, about 10 kilometers above the Earth's surface.

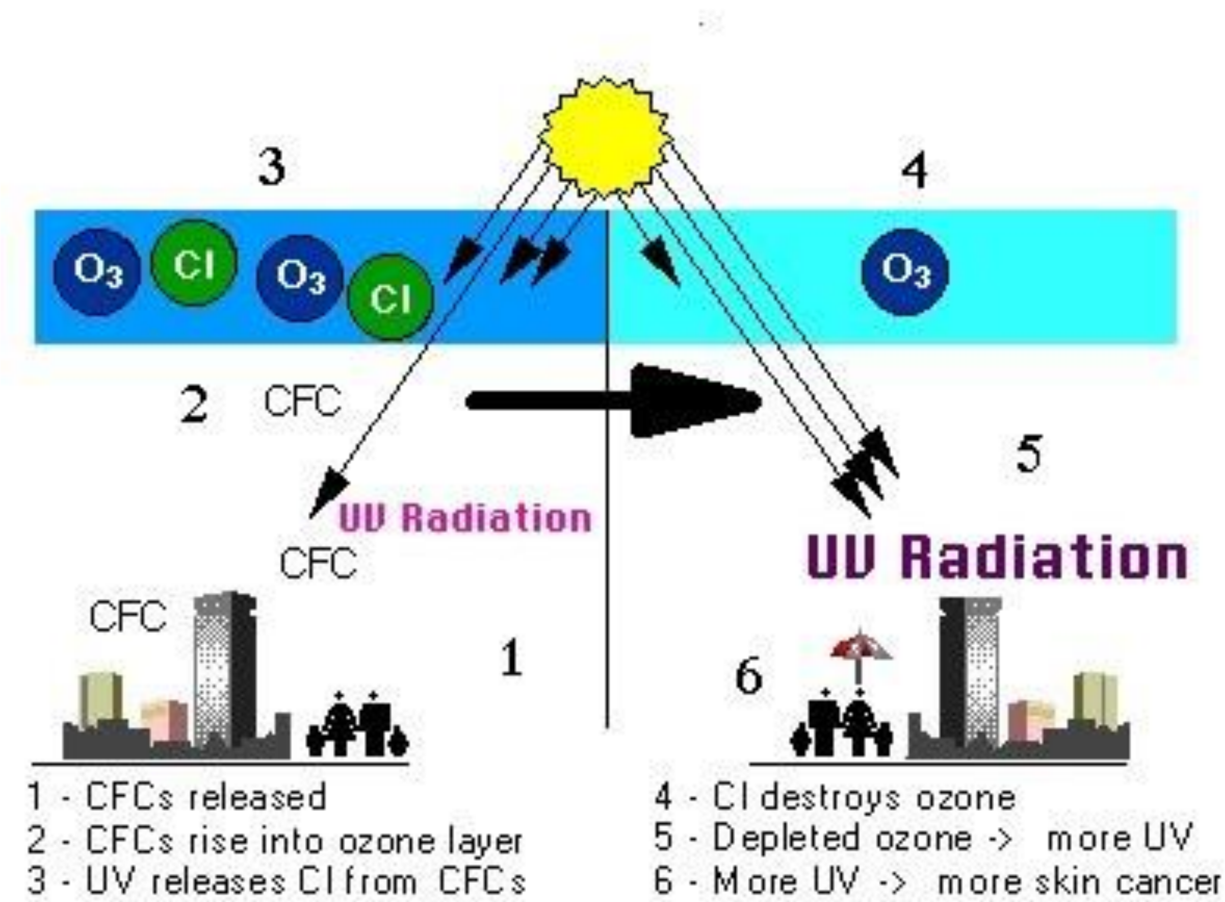


FIGURE 12.2
Strong UV light breaks apart the ODS molecule. CFCs, HCFCs, carbon tetrachloride, methyl chloroform, and other gases release chlorine atoms, and halons and methyl bromide release bromine atoms. It is these atoms that actually destroy ozone, not the intact ODS molecule. It is estimated that one chlorine atom can destroy over 100,000 ozone molecules before it is removed from the stratosphere.

Ozone is constantly produced and destroyed in a natural cycle, as shown in the above picture, courtesy of NASA GSFC. However, the overall amount of ozone is essentially stable. This balance can be thought of as a stream's depth at a partice thought of as a stream's depth at a particular location. Although individual water molecules are moving past the observer, the total depth remains constant. Similarly, while ozone production and destruction are balanced, ozone levels remain stable. This was the situation until the past several decades.

Large increases in stratospheric chlorine and bromine, however, have upset that balance. In effect, they have added a siphon downstream, removing ozone faster than natural ozone creation reactions can keep up. Therefore, ozone levels fall.

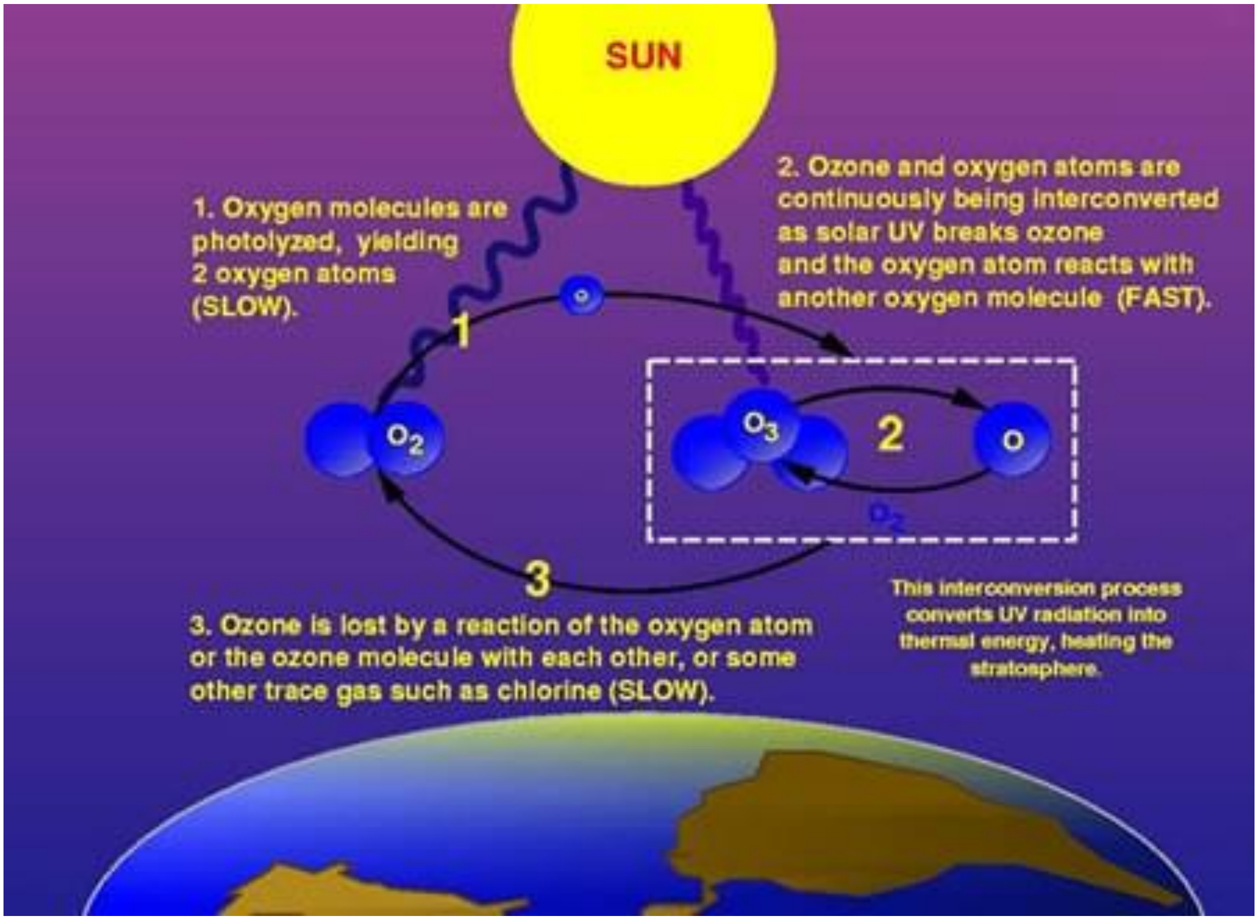


FIGURE 12.3

Since ozone filters out harmful UVB radiation, less ozone means higher UVB levels at the surface. The more the depletion, the larger the increase in incoming UVB. UVB has been linked to skin cancer, cataracts, damage to materials like plastics, and harm to certain crops and marine organisms. Although some UVB reaches the surface even without ozone depletion, its harmful effects will increase as a result of this problem.

### Policies to Reduce Ozone Destruction

One success story in reducing pollutants that harm the atmosphere concerns ozone-destroying chemicals (CK12, 2015). In 1973, scientists calculated that CFCs could reach the stratosphere and break apart. This would release chlorine atoms, which would then destroy ozone. Based only on their calculations, the United States and most Scandinavian countries banned CFCs in spray cans in 1978.

More confirmation that CFCs break down ozone was needed before more was done to reduce production of ozone-destroying chemicals. In 1985, members of the British Antarctic Survey reported that a 50% reduction in the ozone layer had been found over Antarctica in the previous three springs.

Two years after the British Antarctic Survey report, the "Montreal Protocol on Substances that Deplete the Ozone Layer" was ratified by nations all over the world.

The **Montreal Protocol** controls the production and consumption of 96 chemicals that damage the ozone layer ( **Figure** below). Hazardous substances are phased out first by developed nations and one decade later by developing nations. More hazardous substances are phased out more quickly. CFCs have been mostly phased out since 1995, although were used in developing nations until 2010. Some of the less hazardous substances will not be phased out until 2030. The Protocol also requires that wealthier nations donate money to develop technologies that will replace these chemicals.

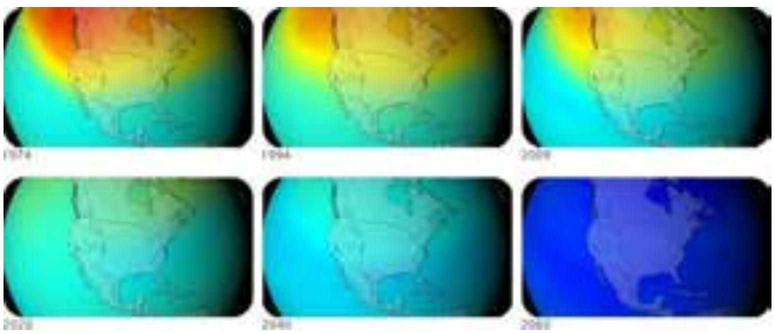

FIGURE 12.4
Map of ozone levels over North America

Since CFCs take many years to reach the stratosphere and can survive there a long time before they break down, the ozone hole will probably continue to grow for some time before it begins to shrink. The ozone layer will reach the same levels it had before 1980 around 2068 and 1950 levels in one or two centuries.

Reductions in stratospheric ozone levels will lead to higher levels of UVB reaching the Earth's surface. The sun's output of UVB does not change; rather, less ozone means less protection, and hence more UVB reaches the Earth.

#### Health and Environmental Effects of Ozone Layer Depletion

*The Connection Between Ozone Layer Depletion and UVB Radiation*

Reductions in stratospheric ozone levels will lead to higher levels of UVB reaching the Earth's surface (EPA, 2015). The sun's output of UVB does not change; rather, less ozone means less protection, and hence more UVB reaches the Earth. Studies have shown that in the Antarctic, the amount of UVB measured at the surface can double during the annual ozone hole.

*Effects on Human Health*

Laboratory and epidemiological studies demonstrate that UVB causes nonmelanoma skin cancer and plays a major role in malignant melanoma development. In addition, UVB has been linked to cataracts – a clouding of the eye's lens. All sunlight contains some UVB, even with normal stratospheric ozone levels. It is always important to protect your skin and eyes from the sun. Ozone layer depletion increases the amount of UVB and the risk of health effects.

*Effects on Plants*

Physiological and developmental processes of plants are affected by UVB radiation, even by the amount of UVB in present-day sunlight. Despite mechanisms to reduce or repair these effects and a limited ability to adapt to increased levels of UVB, plant growth can be directly affected by UVB radiation.

*Effects on Marine Ecosystems*

Phytoplankton form the foundation of aquatic food webs. Phytoplankton productivity is limited to the euphotic zone, the upper layer of the water column in which there is sufficient sunlight to support net productivity. The position of the organisms in the euphotic zone is influenced by the action of wind and waves. In addition, many phytoplankton are capable of active movements that enhance their productivity and, therefore, their survival. Exposure to solar UVB radiation has been shown to affect both orientation mechanisms and motility in phytoplankton, resulting in reduced survival rates for these organisms.

*Effects on Biogeochemical Cycles*

Increases in solar UV radiation could affect terrestrial and aquatic biogeochemical cycles, thus altering both sources and sinks of greenhouse and chemically-important trace gases e.g., carbon dioxide ($CO_2$), carbon monoxide (CO), carbonyl sulfide (COS) and possibly other gases, including ozone. These potential changes would contribute to biosphere-atmosphere feedbacks that attenuate or reinforce the atmospheric buildup of these gases.

## 12.3 Acid Rain

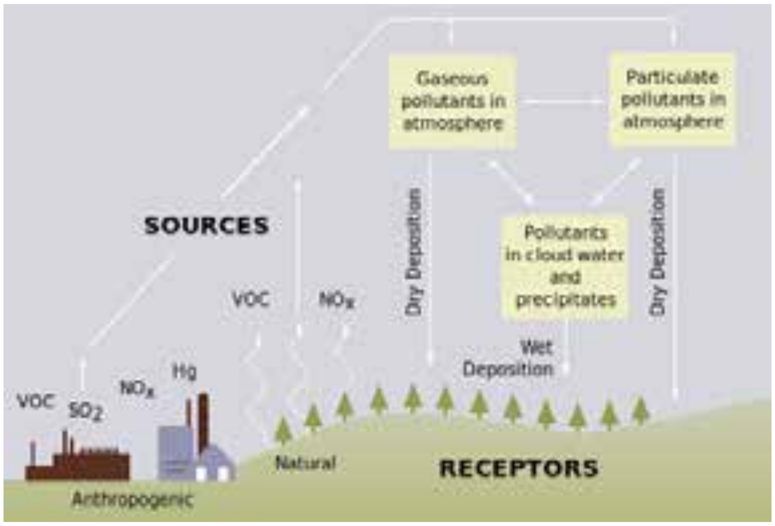


FIGURE 12.5
Processes involved in acid deposition.

Acid rain is a term referring to a mixture of wet and dry deposition (deposited material) from the atmosphere containing higher than normal amounts of nitric and sulfuric acids. The precursors, or chemical forerunners, of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) resulting from fossil fuel combustion. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds. The result is a mild solution of sulfuric acid and nitric acid. When sulfur dioxide and nitrogen oxides are released from power plants and other sources, prevailing winds blow these compounds across state and national borders, sometimes over hundreds of miles.

### Measuring Acid Rain

Acid rain is measured using a scale called "pH." The lower a substance's pH, the more acidic it is. Pure water has a pH of 7.0. However, normal rain is slightly acidic because carbon dioxide ($CO_2$) dissolves into it forming weak carbonic acid, giving the resulting mixture a pH of approximately 5.6 at typical atmospheric concentrations of $CO_2$. As of 2000, the most acidic rain falling in the U.S. has a pH of about 4.3.

### Effects of Acid Rain

Acid rain causes **acidification** of lakes and streams and contributes to the damage of trees at high elevations (for example, red spruce trees above 2,000 feet) and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. Prior to falling to the earth, sulfur dioxide ($SO_2$) and nitrogen oxide ($NO_x$) gases and their particulate matter derivatives—sulfates and nitrates—contribute to visibility degradation and harm public health.

The **ecological** effects of acid rain are most clearly seen in the aquatic, or water, environments, such as streams, lakes, and marshes. Most lakes and streams have a pH between 6 and 8, although some lakes are naturally acidic even without the effects of acid rain. Acid rain primarily affects sensitive bodies of water, which are located in watersheds whose soils have a limited ability to neutralize acidic compounds (called "buffering capacity"). Lakes and streams become acidic (i.e., the pH value goes down) when the water itself and its surrounding soil cannot buffer the acid rain enough to neutralize it. In areas where buffering capacity is low, acid rain releases aluminum from soils into lakes and streams; aluminum is highly toxic to many species of aquatic organisms. Acid rain causes slower growth, injury, or death of **forests**. Of course, acid rain is not the only cause of such conditions. Other factors contribute to the overall stress of these areas, including air pollutants, insects, disease, drought, or very cold weather. In most cases, in fact, the impacts of acid rain on trees are due to the combined effects of acid rain and these other environmental stressors. Acid rain and the dry deposition of acidic particles contribute to the corrosion of **metals** (such as bronze) and the deterioration of paint and stone (such as marble and limestone). These effects significantly reduce the societal value of buildings, bridges, cultural objects (such as statues, monuments, and tombstones), and cars (Figure below).

FIGURE 12.6

A gargoyle that has been damaged by acid rain.

Barbieri, N. (2006). Acid rain damaged gargoyle. (JPG). Retrieved from https://ia.wikipedia.org/wiki/File:-_Acid_rain_damaged_gargoyle_-.jpg

Sulfates and nitrates that form in the atmosphere from sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) emissions contribute to **visibility impairment,** meaning we cannot see as far or as clearly through the air. The pollutants that cause acid rain—sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$)—damage **human health**. These gases interact in the atmosphere to form fine sulfate and nitrate particles that can be transported long distances by winds and inhaled deep into people's lungs. Fine particles can also penetrate indoors. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis.

# 12.4 Climate Change

## Causes of Climate Change

### Earth's Temperature is a Balancing Act

Earth's temperature depends on the balance between energy entering and leaving the planet's system (EPA, 2015). When incoming energy from the sun is absorbed by the Earth system, Earth warms. When the sun's energy is reflected back into space, Earth avoids warming. When energy is released back into space, Earth cools. Many factors, both natural and human, can cause changes in Earth's energy balance, including:

- Changes in the greenhouse effect, which affects the amount of heat retained by Earth's atmosphere
- Variations in the sun's energy reaching Earth
- Changes in the reflectivity of Earth's atmosphere and surface

These factors have caused Earth's climate to change many times.

Scientists have pieced together a picture of Earth's climate, dating back hundreds of thousands of years, by analyzing a number of indirect measures of climate such as ice cores, tree rings, glacier lengths, pollen remains, and ocean sediments, and by studying changes in Earth's orbit around the sun.

The historical record shows that the climate system varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations.

Recent **climate changes,** however, cannot be explained by natural causes alone. Research indicates that natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, human activities can very likely explain most of that warming.[1]

### The greenhouse effect causes the atmosphere to retain heat

When sunlight reaches Earth's surface, it can either be reflected back into space or absorbed by Earth. Once absorbed, the planet releases some of the energy back into the atmosphere as heat (also called infrared radiation). Greenhouse gases (GHGs) like water vapor ($H_2O$), carbon dioxide ($CO_2$), and methane ($CH_4$) absorb energy, slowing or preventing the loss of heat to space. In this way, GHGs act like a blanket, making Earth warmer than it would otherwise be. This process is commonly known as the "greenhouse effect".

TABLE 12.2:

| |
|---|
| **What is Global Warming?** |
| ***Global warming*** refers to the recent and ongoing rise in global average temperature near Earth's surface. It is caused mostly by increasing concentrations of greenhouse gases in the atmosphere. Global warming is causing climate patterns to change. However, global warming itself represents only one aspect of climate change. |
| **What is Climate Change?** |
| ***Climate change*** refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer. |

**Humans are largely responsible for recent climate change**

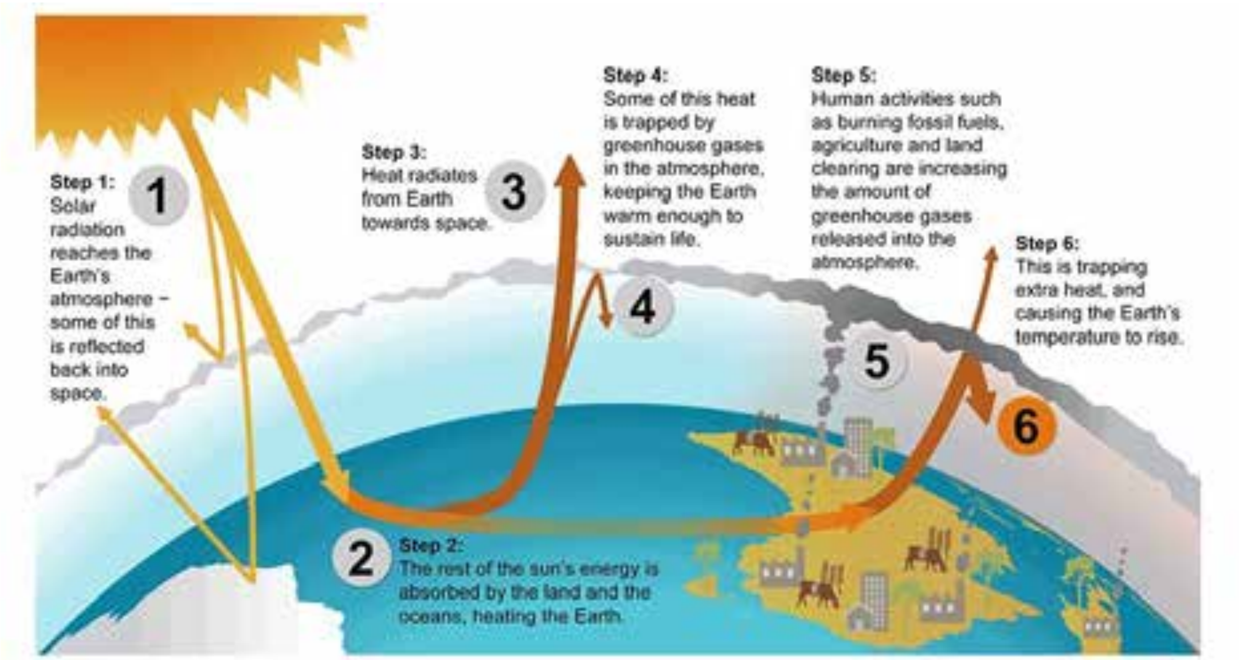


FIGURE 12.7

Enhanced Greenhouse Effect

Department of Agriculture, Water and the Environment. (2019). Greenhouse effect. (JPG). Retrieved from http://www.environment.gov.au/climate-change/climate-science/greenhouse-effect.

### The Main Greenhouse Gasses

The most important GHGs directly emitted by humans include $CO_2$, CH, nitrous oxide ($N_2O$), and several others. The sources and recent trends of these gases are detailed below.

***Carbon dioxide*.** Carbon dioxide ($CO_2$) is the primary greenhouse gas that is contributing to recent climate change. $CO_2$ is absorbed and emitted naturally as part of the carbon cycle, through animal and plant respiration, volcanic eruptions, and ocean-atmosphere exchange. Human activities, such as the burning of fossil fuels and changes in land use, release large amounts of carbon to the atmosphere, causing $CO_2$ concentrations in the atmosphere to rise.

Atmospheric $CO_2$ concentrations have increased by almost 40% since pre-industrial times, from approximately 280 parts per million by volume (ppmv) in the 18th century to 390 ppmv in 2010. The current $CO_2$ level is higher than it has been in at least 800,000 years.[1]Some volcanic eruptions released large quantities of $CO_2$ in the distant past. However, the U.S.Geological Survey (USGS) reports that human activities now emit more than 135 times as much $CO_2$ as volcanoes each year. Human activities currently release over 30 billion tons of $CO_2$ into the atmosphere every year.[1]This build-up in the atmosphere is like a tub filling with water, where more water flows from the faucet than the drain can take away.

**Methane**. Methane ($CH_4$) is produced through both natural and human activities. For example, natural wetlands, agricultural activities, and fossil fuel extraction and transport all emit $CH_4$.

Methane is more abundant in Earth's atmosphere now than at any time in at least the past 650,000 years.[2]Due to human activities, $CH_4$concentrations increased sharply during most of the 20th century and are now more than two and-a-half times pre-industrial levels. In recent decades, the rate of increase has slowed considerably.[1]

**Nitrous oxide**. Nitrous oxide ($N_2O$) is produced through natural and human activities, mainly through agricultural activities and natural biological processes. Fuel burning and some other processes also create $N_2O$. Concentrations of $N_2O$ have risen approximately 18% since the start of the Industrial Revolution, with a relatively rapid increase towards the end of the 20th century.[3]In contrast, the atmospheric concentration of $N_2O$ varied only slightly for a period of 11,500 years before the onset of the industrial period, as shown by ice core samples.

**Other Greenhouse Gasses**

Water vapor is the most abundant greenhouse gas and also the most important in terms of its contribution to the natural greenhouse effect, despite having a short atmospheric lifetime. Some human activities can influence local water vapor levels. However, on a global scale, the concentration of water vapor is controlled by temperature, which influences overall rates of evaporation and precipitation.[1]Therefore, the global concentration of water vapor is not substantially affected by direct human emissions.

Tropospheric ozone (O3), which also has a short atmospheric lifetime, is a potent greenhouse gas. Chemical reactions create ozone from emissions of nitrogen oxides and volatile organic compounds from automobiles, power plants, and other industrial and commercial sources in the presence of sunlight. In addition to trapping heat, ozone is a pollutant that can cause respiratory health problems and damage crops and ecosystems.

Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), together called F-gases, are often used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Unlike water vapor and ozone, these F-gases have a long atmospheric lifetime, and some of these emissions will affect the climate for many decades or centuries.

### Changes in the sun's energy affect how much energy reaches Earth's system

Climate is influenced by natural changes that affect how much solar energy reaches Earth. These changes include changes within the sun and changes in Earth's orbit. Changes occurring in the sun itself can affect the intensity of the sunlight that reaches Earth's surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity). The sun follows a natural 11-year cycle of small ups and downs in intensity, but the effect on Earth's climate is small. Changes in the shape of Earth's orbit as well as the tilt and position of Earth's axis can also affect the amount of sunlight reaching Earth's surface.

Changes in the sun's intensity have influenced Earth's climate in the past. For example, the so-called "Little Ice Age" between the 17th and 19th centuries may have been partially caused by a low solar activity phase from 1645 to 1715, which coincided with cooler temperatures. The "Little Ice Age" refers to a slight cooling of North America, Europe, and probably other areas around the globe.

Changes in Earth's orbit have had a big impact on climate over tens of thousands of years. In fact, the amount of summer sunshine on the Northern Hemisphere, which is affected by changes in the planet's orbit, appears to control the advance and retreat of ice sheets. These changes appear to be the primary cause of past cycles of ice ages, in which Earth has experienced long periods of cold temperatures (ice ages), as well as shorter interglacial periods (periods between ice ages) of relatively warmer temperatures.

Changes in solar energy continue to affect climate. However, solar activity has been relatively constant, aside from the 11-year cycle, since the mid-20th century and therefore does not explain the recent warming of Earth. Similarly, changes in the shape of Earth's orbit as well as the tilt and position of Earth's axis affect temperature on relatively long timescales (tens of thousands of years), and therefore cannot explain the recent warming.

### Changes in reflectivity affect how much energy enters Earth's system

When sunlight reaches Earth, it can be reflected or absorbed. The amount that is reflected or absorbed depends on Earth's surface and atmosphere. Light-colored objects and surfaces, like snow and clouds, tend to reflect most sunlight, while darker objects and surfaces, like the ocean, forests, or soil, tend to absorb more sunlight.

The term **albedo** refers to the amount of solar radiation reflected from an object or surface, often expressed as a percentage. Earth as a whole has an albedo of about 30%, meaning that 70% of the sunlight that reaches the planet is absorbed.[1] Absorbed sunlight warms Earth's land, water, and atmosphere.

Reflectivity is also affected by aerosols. Aerosols are small particles or liquid droplets in the atmosphere that can absorb or reflect sunlight. Unlike greenhouse gases (GHGs), the climate effects of aerosols vary depending on what they are made of and where they are emitted. Those aerosols that reflect sunlight, such as particles from volcanic eruptions or sulfur emissions from burning coal, have a cooling effect. Those that absorb sunlight, such as black carbon (a part of soot), have a warming effect.

### The Role of Reflectivity in the Past

Natural changes in reflectivity, like the melting of sea ice or increases in cloud cover, have contributed to climate change in the past, often acting as feedbacks to other processes.

Volcanoes have played a noticeable role in climate. Volcanic particles that reach the upper atmosphere can reflect enough sunlight back to space to cool the surface of the planet by a few tenths of a degree for several years.[1] These particles are an example of cooling aerosols. Volcanic particles from a single eruption do not produce long-term change because they remain in the atmosphere for a much shorter time than GHGs.[1][7]

### The Recent Role of Reflectivity

**Human changes** in land use and land cover have changed Earth's reflectivity. Processes such as deforestation, reforestation, desertification, and urbanization often contribute to changes in climate in the places they occur. These effects may be significant regionally, but are smaller when averaged over the entire globe.

In addition, human activities have generally increased the number of aerosol particles in the atmosphere. Overall, human-generated aerosols have a net cooling effect offsetting about one-third of the total warming effect associated with human greenhouse gas emissions. Reductions in overall aerosol emissions can therefore lead to more warming. However, targeted reductions in black carbon emissions can reduce warming.

### Is there a scientific consensus on climate change?

The major scientific agencies of the United States — including the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) — agree that climate change is occurring and that humans are contributing to it. In 2010, the National Research Council concluded that "Climate change is occurring, is very likely caused by human activities, and poses significant risks for a broad range of human and natural systems". Many independent scientific organizations have released similar statements, both in the United States and abroad. This doesn't necessarily mean that every scientist sees eye to eye on each component of the climate change problem, but broad agreement exists that climate change is happening and is primarily caused by excess greenhouse gases from human activities.

## Future Climate Change

### Increasing greenhouse gas concentrations will have many effects

Greenhouse gas concentrations in the atmosphere will continue to increase unless the billions of tons of our annual emissions decrease substantially (EPA, 2015). Increased concentrations are expected to:

- Increase Earth's average temperature

- Influence the patterns and amounts of precipitation
- Reduce ice and snow cover, as well as permafrost
- Raise sea level
- Increase the acidity of the oceans

These changes will impact our food supply, water resources, infrastructure, ecosystems, and even our own health

### Future changes will depend on many factors

The magnitude and rate of future climate change will primarily depend on the following factors:

- The rate at which levels of greenhouse gas concentrations in our atmosphere continue to increase
- How strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected increase in greenhouse gas concentrations
- Natural influences on climate (e.g., from volcanic activity and changes in the sun's intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns)

### Past and present-day greenhouse gas emissions will affect climate far into the future

Many greenhouse gases stay in the atmosphere for long periods of time (EPA, 2015). As a result, even if emissions stopped in- creasing, atmospheric greenhouse gas concentrations would continue to increase and remain elevated for hundreds of years. Moreover, if we stabilized concentrations and the composition of today's atmosphere remained steady (which would require a dramatic reduction in current greenhouse gas emissions), surface air temperatures would continue to warm. This is because the oceans, which store heat, take many decades to fully respond to higher greenhouse gas concentrations. The ocean's response to higher greenhouse gas concentrations and higher temperatures will continue to impact climate over the next several decades to hundreds of years.[1][2]

Because it is difficult to project far-off future emissions and other human factors that influence climate, scientists use a range of scenarios using various assumptions about future economic, social, technological, and environmental conditions.

### Future Temperature Changes

We have already observed global warming over the last several decades. Future temperatures are expected to change further. Climate models project the following key temperature-related changes.

*Key Global Projections*

- Average global temperatures are expected to increase by 2 °F to 11.5°F by 2100, depending on the level of future greenhouse gas emissions, and the outcomes from various climate models.[3]
- By 2100, global average temperature is expected to warm at least twice as much as it has during the last 100 years.[2]
- Ground-level air temperatures are expected to continue to warm more rapidly over land than oceans.[2]
- Some parts of the world are projected to see larger temperature increases than the global average.[2]

## Future Precipitation and Storm Events

Patterns of precipitation and storm events, including both rain and snowfall are also likely to change. However, some of these changes are less certain than the changes associated with temperature. Projections show that future precipitation and storm changes will vary by season and region. Some regions may have less precipitation, some may

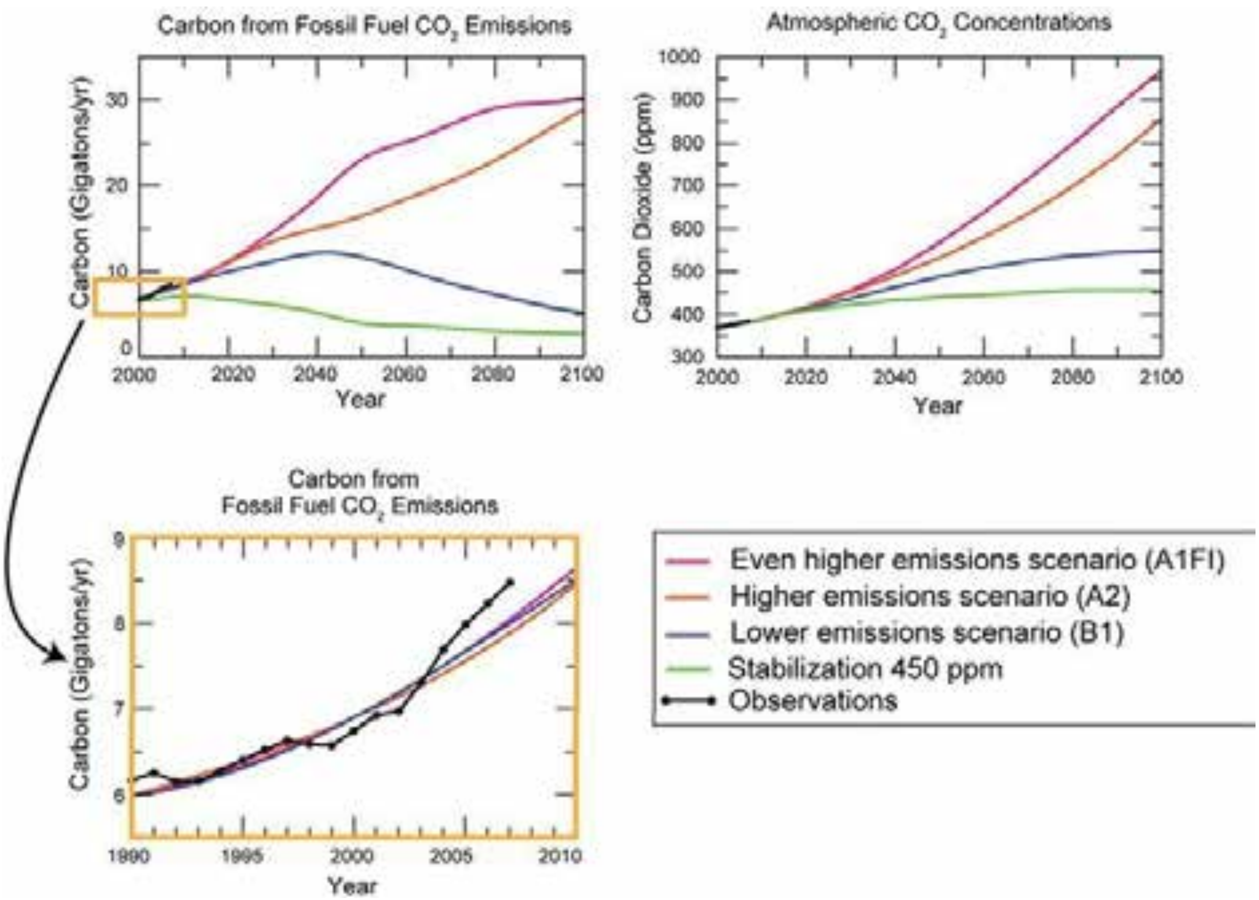


FIGURE 12.8

This figure shows projected greenhouse gas concentrations for four different emissions scenarios. The top three scenarios assume no explicit climate policies. The bottom green line is an illustrative "stabilization scenario," designed to stabilize atmospheric carbon dioxide concentration at 450 parts per million by volume (ppmv). Source: USGCRP (2009)

have more precipitation, and some may have little or no change. The amount of rain falling in heavy precipitation events is likely to increase in most regions, while storm tracks are projected to shift poleward. [4] Climate models project the following precipitation and storm changes

*Key Global Projections*

- Global average annual precipitation through the end of the century is expected to increase, although changes in the amount and intensity of precipitation will vary by region.
- The intensity of precipitation events will likely increase on average. This will be particularly pronounced in tropical and high-latitude regions, which are also expected to experience overall increases in precipitation.[4]

- The strength of the winds associated with tropical storms is likely to increase. The amount of precipitation falling in tropical storms is also likely to increase.[5]
- Annual average precipitation is projected to increase in some areas and decrease in others. The figure to the right shows projected regional differences in precipitation for summer and winter.[6]

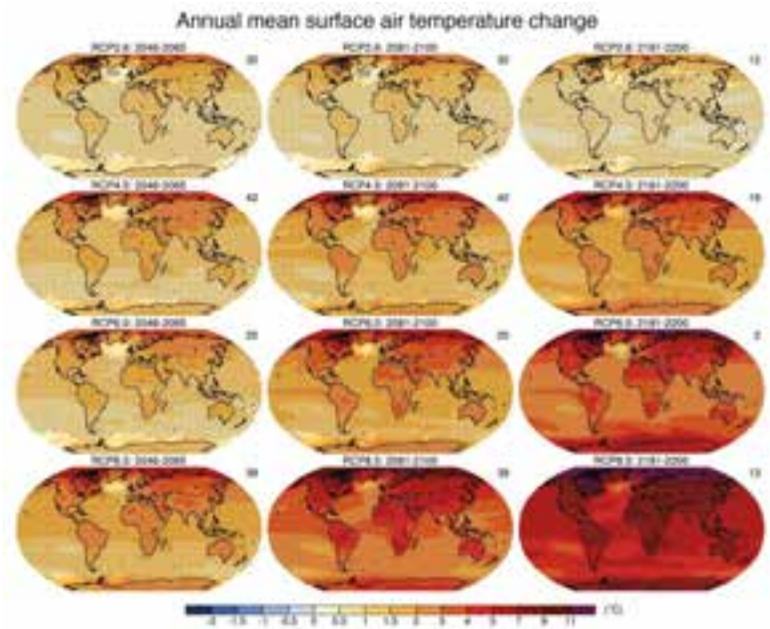


FIGURE 12.9

Projected changes in global average temperatures under three emissions scenarios (rows) for three different time periods (columns). Changes in temperatures are relative to 1961-1990 averages. The scenarios come from the IPCC Special Report on Emissions Scenarios: B1 is a low emissions scenario, A1B is a medium-high emissions scenario, and A2 is a high emissions scenario. Source: NRC 2010

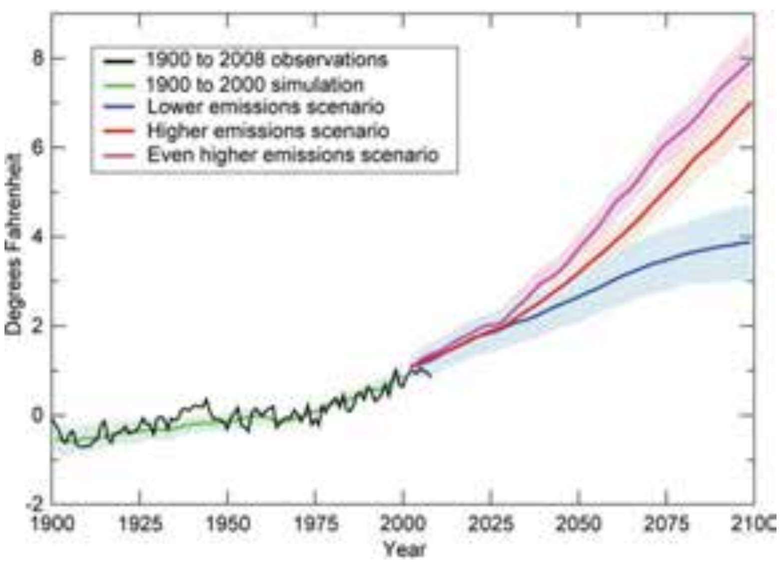


FIGURE 12.10

Observed and projected changes in global average temperature under three no-policy emissions scenarios. The shaded areas show the likely ranges while the lines show the central projections from a set of climate models. A wider range of model types shows outcomes from 2 to 11.5˚F. Changes are relative to the 1960-1979 average. Source: USGCRP 2009

### Future Ice, Snowpack, and Permafrost

Arctic sea ice is already declining.[7] The area of snow cover in the Northern Hemisphere has decreased since about 1970.[7] Permafrost temperature has increased over the last century.[7] These are just three of the many forms of snow and ice found on Earth. To learn more about the different forms of snow and ice and how they affect the global climate system, visit the Snow and Icepage of the Indicators section. Over the next century, it is expected that sea ice will continue to decline, glaciers will continue to shrink, snow cover will continue to decrease, and permafrost will continue to thaw. Potential changes to ice, snow, and permafrost are described below.

*Key Global Projections*

For every 2˚F of warming, models project about a 15% decrease in the extent of annually averaged sea ice and a

25% decrease in September Arctic sea ice.[7] The coastal sections of the Greenland and Antarctic ice sheets are expected to continue to melt or slide into the ocean. If the rate of this ice melting increases in the 21st century, the ice sheets could add significantly to global sea level rise.[7] Glaciers are expected to continue to decrease in size. The rate of melting is expected to continue to increase, which will contribute to sea level rise.[7]

### Future Sea Level Change

Warming temperatures contribute to sea level rise by: expanding ocean water; melting mountain glaciers and ice caps; and causing portions of the Greenland and Antarctic ice sheets to melt or flow into the ocean.[7] Since 1870, global sea level has risen by about 8 inches.[5] Estimates of future sea level rise vary for different regions, but global sea level for the next century is expected to rise at a greater rate than during the past 50 years.[8] The contribution of thermal expansion, ice caps, and small glaciers to sea level rise is relatively well-studied, but the impacts of climate change on ice sheets are less understood and represent an active area of research. Thus it is more difficult to predict how much changes in ice sheets will contribute to sea level rise.[7] Greenland and Antarctic ice sheets could contribute an additional 1 foot of sea level rise, depending on how the ice sheets respond.

Regional and local factors will influence future relative sea level rise for specific coastlines around the world. For example, relative sea level rise depends on land elevation changes that occur as a result of subsidence (sinking) or uplift (rising). Assuming that these historical geological forces continue, a 2-foot rise in global sea level by 2100 would result in the following relative sea level rise:

- 2.3 feet at New York City
- 2.9 feet at Hampton Roads, Virginia
- 3.5 feet at Galveston, Texas
- 1 foot at Neah Bay in Washington state

Relative sea level rise also depends on local changes in currents, winds, salinity, and water temperatures, as well as proximity to thinning ice sheets.

### Future Ocean Acidification

Corals require the right combination of temperature, light, and the presence of calcium carbonate (which they use to build their skeletons). As atmospheric carbon dioxide ($CO_2$) levels rise, some of the excess $CO_2$ dissolves into ocean water, reducing its calcium carbonate saturation. As the maps indicate, calcium carbonate saturation has already been reduced considerably from its pre-industrial level, and model projections suggest much greater reductions in the future. The blue dots indicate current coral reefs. Note that under projections for the future, it is very unlikely that calcium carbonate saturation levels will be adequate to support coral reefs in any U.S. waters.

Oceans become more acidic as carbon dioxide ($CO_2$) emissions in the atmosphere dissolve in the ocean. This change is measured on the pH scale, with lower values being more acidic. The pH level of the oceans has decreased by approximately 0.1 pH units since pre-industrial times, which is equivalent to a 25% increase in acidity. The pH level of the oceans is projected to decrease even more by the end of the century as $CO_2$ concentrations are expected to increase for the foreseeable future. Ocean acidification adversely affects many marine species, including plankton, mollusks, shellfish, and corals. As ocean acidification increases, the availability of calcium carbonate will decline. Calcium carbonate is a key building block for the shells and skeletons of many marine organisms. If atmospheric $CO_2$ concentrations double, coral calcification rates are projected to decline by more than 30%. If $CO_2$ concentrations continue to rise at their current rate, corals could become rare on tropical and subtropical reefs by 2050.

### Climate change affects everyone

**Our lives are connected to the climate.** Human societies have adapted to the relatively stable climate we have enjoyed since the last ice age which ended several thousand years ago. A warming climate will bring changes that can affect our water supplies, agriculture, power and transportation systems, the natural environment, and even our own health and safety.

**Some changes to the climate are unavoidable.** Carbon dioxide can stay in the atmosphere for nearly a century, so Earth will continue to warm in the coming decades. The warmer it gets, the greater the risk for more severe changes to the climate and Earth's system. Although it's difficult to predict the exact impacts of climate change, what's clear is that the climate we are accustomed to is no longer a reliable guide for what to expect in the future.

**We can reduce the risks we will face from climate change.** By making choices that reduce greenhouse gas pollution, and preparing for the changes that are already underway, we can reduce risks from climate change. Our decisions today will shape the world our children and grandchildren will live in.

## You Can Take Action

You can take steps at home, on the road, and in your office to reduce greenhouse gas emissions and the risks associated with climate change (EPA, 2015). Many of these steps can save you money; some, such as walking or biking to work can even improve your health! You can also get involved on a local or state level to support energy efficiency, clean energy programs, or other climate programs.

Learn more about what you can do.

Calculate your carbon footprint and find ways to reduce your emissions through simple everyday actions.

# 12.5 Climate Change Policies and Adaptation Measures

## Climate Change Policies

According to the Intergovernmental Panel on Climate Change (IPCC), to keep global warming below 2˚C, emissions of carbon dioxide (CO2) and other greenhouse gases must be halved by 2050 (compared with 1990 levels). Developed countries will need to reduce more – between 80% and 95% by 2050; advanced developing countries with large emissions (e.g. China, India and Brazil) will have to limit their emission growth.

Agreed in 1997, the UNFCCC's Kyoto Protocol is a first step towards achieving more substantial global emission reductions (University of California College Prep, 2012). It sets binding emission targets for developed countries that have ratified it, such as the European Union (EU) Member States, and limits the emission increases of the remaining countries for the first commitment period from 2008 to 2012. The 15 pre-2004 EU Member States (the EU-15) have a joint emission reduction target of 8 % below 1990 levels. Through the internal EU "burden-sharing agreement", some EU Member States are permitted increases in emissions, while others must decrease them. Most Member States that joined the EU after 1 May 2004 have targets of -6 % to -8 % from their base years (mostly 1990).

EU emissions represent about 10% of total global emissions. The United States, which has a large share of total global GHG emissions, has not ratified the protocol. China and several other countries with large GHG emissions do not have binding emission targets under the protocol. Countries are expected to meet their target mainly through domestic policies and measures. They may meet part of their emission reduction targets by investing in emission-reducing projects in developing countries (the Clean Development Mechanism (CDM)) or in developed ones (Joint Implementation (JI)). The CDM is also meant to support sustainable development, e.g. by financing renewable energy projects.

The **Cancún Agreements**, adopted at the UN Climate Conference in Mexico (December 2010), include a comprehensive finance, technology and capacity-building support package to help developing nations adapt to climate change and adopt sustainable paths to low-emission economies. The agreements also include a time schedule for reviewing the objective of keeping the average global temperature rise below 2 ˚C. The agreements confirm that developed countries will mobilize USD 100 billion in climate funding for developing countries annually by 2020, and establish a Green Climate Fund through which much of the funding will be channeled.

The **Durban Platform for Enhanced Action**, adopted at the UN conference in South Africa (Dec 2011) agreed a roadmap towards a new legal framework by 2015, applicable to all Parties to the UN climate convention. It also foresees a second commitment period of the Kyoto Protocol, starting in 2013. Agreement was also reached on the design and governance arrangements for the new **Green Climate Fund**.

## Adaptation to Climate Change

Adaptation means anticipating the effects of climate change and taking appropriate action to prevent or minimize the damage they can cause or exploit opportunities. Early action will save on damage costs later. Adaptation strategies are needed at all levels of administration, from the local to the international level.

Adaptation affects most economic sectors and involves many levels of decision-making. It should be increasingly integrated in numerous policy areas: disaster risk reduction, coastal zone management, agriculture and rural development, health services, spatial planning, regional development, ecosystems and water management. Low-regret measures (suitable under every plausible scenario) and a variety of adaptation options should be considered, e.g. technological measures, ecosystem-based measures, and measures addressing behavioral changes.

Adaptation measures include using scarce water resources more efficiently, adapting building codes to future climate conditions and extreme weather events, building flood defences and raising the levels of dykes, developing drought-tolerant crops, choosing tree species and forestry practices less vulnerable to storms and fires, and setting aside land corridors to help species migrate.

## 12.6 Case Study: Two Climate Action Plans

### Introduction

If increased greenhouse gas emissions from human activity are causing climate change, then how do we reduce those emissions? Whether dictated by an international, national, or local regulation or a voluntary agreement, plans are needed to move to a low-carbon economy. In the absence of federal regulation, cities, states, government institutions, and colleges and universities, have all taken climate action initiatives. This case study provides two examples of climate action plans – one for a city (Chicago) and one for an institution (the University of Illinois at Chicago).

### Chicago's Climate Action Plan

Urban areas produce a lot of waste. In fact, 75 percent of all greenhouse gas emissions are generated in urban areas. Therefore, it is important for cities to develop plans to address environmental issues. The Chicago Climate Action Plan (Chicago CAP) is one such example. The mid-term goal of this plan is a 25 percent reduction in greenhouse gas emissions by 2020 and final goal is 80 percent reduction below 1990 GHG levels by the year 2050.

The Chicago CAP outlines several benefits of a climate action plan. The first would obviously be the reduction of the effects of climate change. Under a higher emissions scenario as per the Intergovernmental Panel on Climate Change (IPCC), it is predicted that the number of 100 degree Fahrenheit days per year would increase to 31, under the lower emissions scenario it would only be eight. Established by the United Nations Environment Programme (UNEP), the IPCC is the leading international body that assesses climate change through the contributions of thousands of scientists.

Second, there is an economic benefit derived from increased efficiencies that reduce energy and water consumption. Third, local governments and agencies have great influence over their city's greenhouse gas emissions and can enhance energy efficiency of buildings through codes and ordinances so they play a key role in climate action at all governmental levels. Finally, reducing our dependence on fossil fuels helps the United States achieve energy independence.

A good climate action plan includes reporting of greenhouse gas emissions, as far back as there is data, preferably to 1990. Figure 12.11 depicts the emissions calculated for Chicago through 2005. From that point there is an estimate (the dotted line) of a further increase before the reductions become evident and the goals portrayed can be obtained. The plan was released in September 2008 and provides a roadmap of five strategies with 35 actions to reduce greenhouse gas emissions (GHG) and adapt to climate change. Figure 12.12 identifies the proportion of emissions reductions from the various strategies.

In 2010 CCAP put out a progress report wherein progress is measured by the many small steps that are being taken to implement the plan. It is not translated exactly to emissions reductions but reports on progress for each step such as the number of residential units that have been retrofitted for energy efficiency, the number of appliances traded in, the increase in the number of rides on public transit, and the amount of water conserved daily.

### University Climate Action Plan

Several factors caused a major Chicago university to develop a climate action plan. As part of the American College and University Presidents' Climate Commitment (ACUPCC), nearly 670 presidents have signed a commitment to inventory their greenhouse gases, publicly report it, and to develop a climate action plan. Part of the Chicago CAP is to engage businesses and organizations within the city in climate action planning. In order to be a better steward

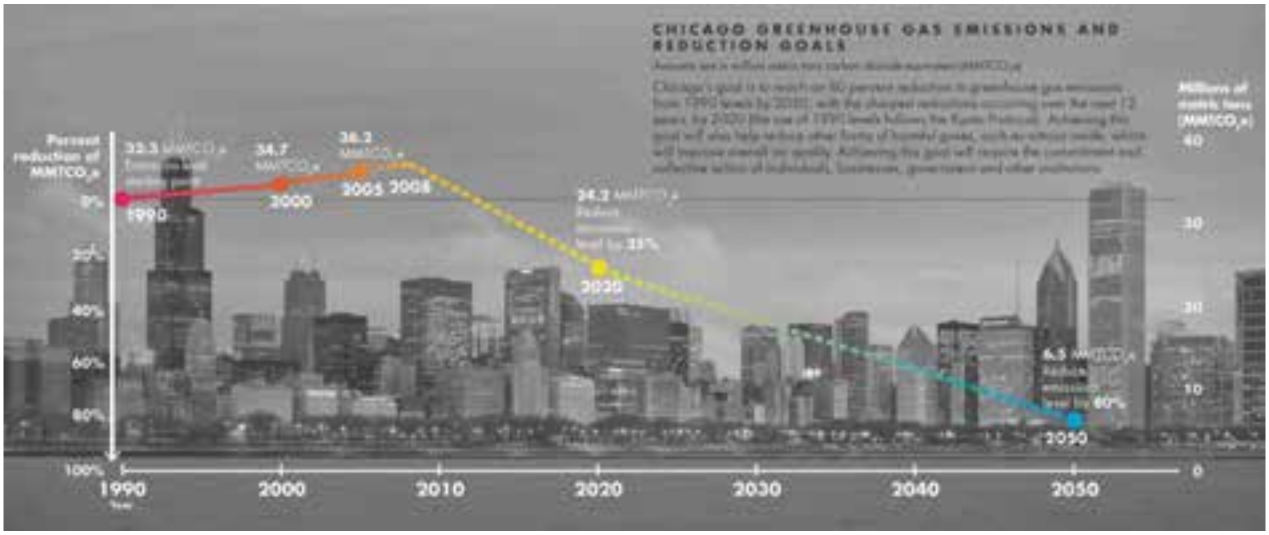


FIGURE 12.11

Chicago Greenhouse Gas Emissions and Reduction Goals Figure illustrates the emissions calculated for Chicago through 2005. Source: City of Chicago, Chicago Climate Action Plan

of the environment, the University of Illinois at Chicago (UIC) developed a climate action plan. The goals are similar to Chicago's: a 40 percent GHG emissions reduction by 2030 and at least 80 percent by 2050, using a 2004 baseline. The strategies align with those of the city in which the campus resides (see Table Alignment of the Chicago and UIC Climate Action Plans). UIC's greenhouse gas reports are also made publically available on the ACUPCC reporting site. Figure 12.13 displays UIC's calculated emissions inventory (in red) and then the predicted increases for growth if activities continue in a "business as usual (BAU)" approach. The triangular wedges below represent emissions reductions through a variety of strategies, similar to those of the wedge approach that Professors Sokolow and Pacala proposed. Those strategies are displayed in Table Alignment of the Chicago and UIC Climate Action Plans, alongside Chicago's for comparative purposes.

The UIC CAP also has major strategy categories that are similar to Chicago's and within each strategy there are a number of recommended actions. Progress on this plan will be monitored both by reporting emissions at least every two years to the ACUPCC and by tracking individual actions and reporting to the campus community.

**TABLE 12.3:** Alignment of the Chicago and UIC Climate Action Plans

| CHICAGO CAP | UIC CAP |
|---|---|
| **Energy Efficient Buildings** | **Energy Efficiency and Conservation** |
| Retrofit commercial and industrial buildings | Retrofit buildings |
| Retrofit residential buildings | Energy performance contracting |
| Trade in appliances | Monitoring and maintenance |
| Conserve water | Water conservation |
| Update City energy code | Establish green building standards |
| Establish new guidelines for renovations | |
| Cool with trees and green roofs | Green roofs/reflective roofs |
| Take easy steps | Energy conservation by campus community |
| **Clean & Renewable Energy Sources** | **Clean and Renewable Energy** |
| Upgrade power plants | Modify power plants |

**TABLE 12.3:** (continued)

| | |
|---|---|
| Improve power plant efficiency | Purchase electricity from a renewable electricity provider |
| Build renewable electricity | Build renewable electricity |
| Increase distributed generation | |
| Promote household renewable power | Geothermal heating and cooling |
| **Improved Transportation Options** | **Improved Transportation Options** |
| Invest more in transit | |
| Expand transit incentives | Expand transit incentives |
| Promote transit-oriented development | |
| Make walking and biking easier | Make walking and biking easier |
| Car share and car pool | Car sharing/car pool program |
| Improve fleet efficiency | Continue to improve fleet efficiency |
| Achieve higher fuel efficiency standards | |
| Switch to cleaner fuels | |
| Support intercity rail | Reduce business travel (web conferencing) |
| Improve freight movement | Anti-Idling regulations/guidelines |
| **Reduced Waste & Industrial Pollution** | **Recycling and Waste Management** |
| Reduce, reuse and recycle | Establishing recycling goals |
| Shift to alternative refrigerants | Composting |
| Capture stormwater on site | Sustainable food purchases & use of biodegradable packaging |
| | Collecting and converting vegetable oil |
| | Develop a user-friendly property management system |
| | Expand the waste minimization program |
| | Recycle construction debris |
| | Purchasing policies |
| **Preparation (Adaptation)** | **Improved Grounds Operations** |
| Manage heat | Capture stormwater on site |
| Protect air quality | Use native species |
| Manage stormwater | Reduce/eliminate irrigation |
| Implement green urban design | Integrated pest management |
| Preserve plants and trees | Tree care plan |
| Pursue innovative cooling | |
| Engage the public | **Education, Research and Public Engagement** |
| Engage businesses | **Employment Strategies** |
| Plan for the future | Telecommuting |
| | Flextime |
| | Childcare center |
| | Public Engagement |

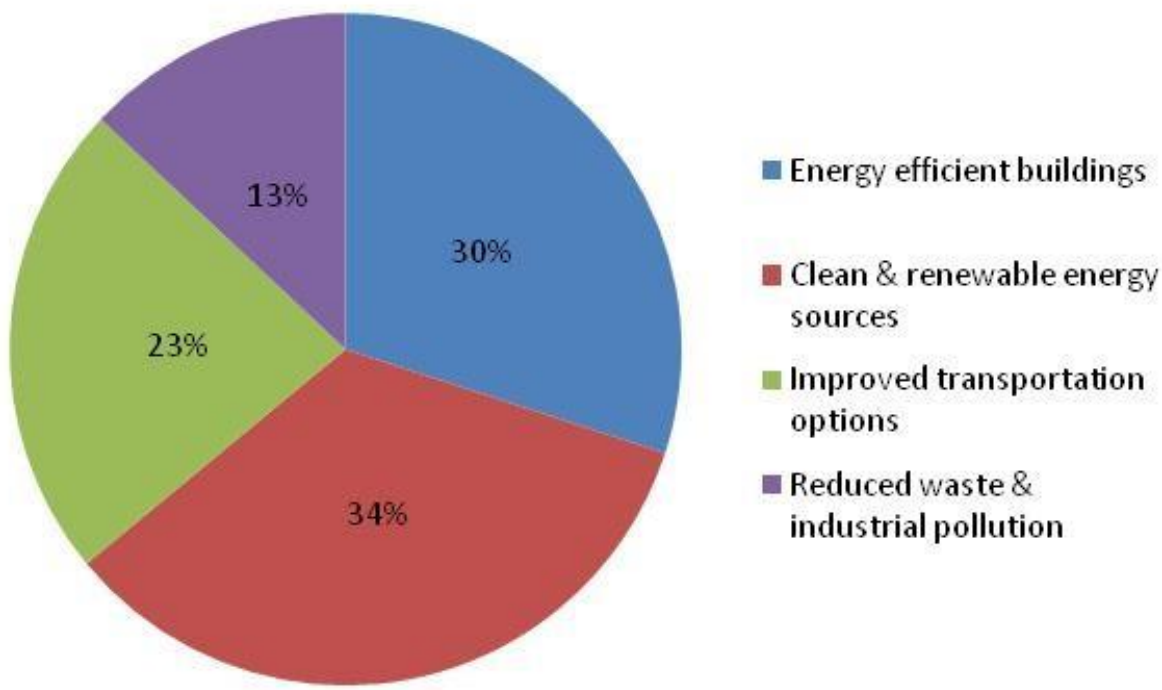


FIGURE 12.12

Graph shows the sources of the Chicago CAP emission reductions by strategy. Source: C. Klein-Banai using data from City of Chicago, Chicago Climate Action Plan.

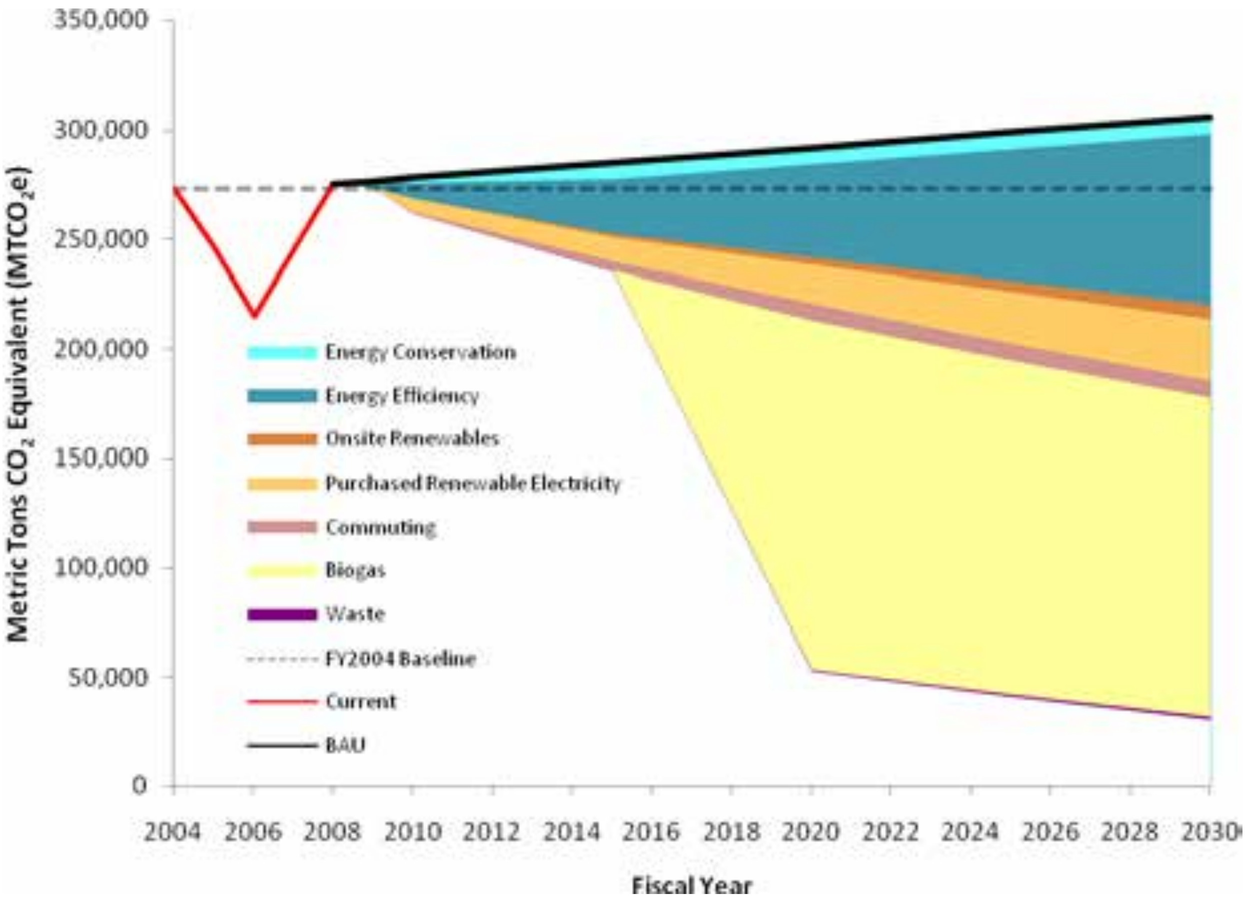


FIGURE 12.13

UIC's Projected Emissions Reductions Projected emissions reductions from 2004 to 2030. Where BAU stands for Business as Usual, what would happen if no action were taken? Source: UIC Climate Action Plan, figure 6.

## Conclusion

There is no one approach that will effectively reduce greenhouse gas emissions. Climate action plans are helpful tools to represent strategies to reduce emissions. Governmental entities such as nations, states, and cities can develop plans, as can institutions and businesses. It is important that there be an alignment of plans when they intersect, such as a city and a university that resides within it.

# 12.7 Resources

## Summary

Air pollution can be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Chemicals discharged into the air that have a direct impact on the environment are called primary pollutants. These primary pollutants sometimes react with other chemicals in the air to produce secondary pollutants. The commonly found air pollutants, known as criteria pollutants, are particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. These pollutants can harm health and the environment, and cause property damage. The historical record shows that the climate system varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas concentrations. Recent climate changes, however, cannot be explained by natural causes alone. Natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, human activities can explain most of that warming. The primary human activity affecting the amount and rate of climate change is greenhouse gas emissions from the burning of fossil fuels. Greenhouse gas concentrations in the atmosphere will continue to increase unless the billions of tons of our annual emissions decrease substantially. Increased concentrations are expected to increase Earth's average temperature, influence the patterns and amounts of precipitation, reduce ice and snow cover, as well as permafrost, raise sea level and increase the acidity of the oceans. These changes will impact our food supply, water resources, infrastructure, ecosystems, and even our own health. Acid rain is a term referring to a mixture of wet and dry deposition from the atmosphere containing higher than normal amounts of nitric and sulfuric acids. The precursors of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx) resulting from fossil fuel combustion. Acid rain causes acidification of lakes and streams, contributes to the damage of trees and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, contributes to the corrosion of metals and damages human health. The ozone depletion process begins when CFCs and other ozone- depleting substances (ODS) are emitted into the atmosphere. Reductions in stratospheric ozone levels lead to higher levels of UVB reaching the Earth's surface. The sun's output of UVB does not change; rather, less ozone means less protection, and hence more UVB reaches the Earth. Ozone layer depletion increases the amount of UVB tat lead to negative health and environmental effects.

## Review Questions

1.What are the major air pollution sources?
2.What are the causes of sick building syndrome?
3.Why is secondhand smoke dangerous?
4. Why is EPA is concerned about particles that are 10 micrometers in diameter or smaller?
5. What are some possible effects of climate change?
6. What are the major kinds of ozone depleting substances?

# 12.8 References

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# CHAPTER 13 Water Availability and Use

## Chapter Outline



FIGURE 13.1

Great Lakes from Space. The Great Lakes hold 21% of the world's surface fresh water. Lakes are an important surface water resource.

## Learning Outcomes

After studying this chapter, you should be able to:

- Understand how the water cycle operates
- Know the causes and effects of depletion in different water reservoirs
- Understand how we can work toward solving the water supply crisis
- Understand the major kinds of water pollutants and how they degrade water quality
- Understand how we can work toward solving the crisis involving water pollution

# 13.1 Water Cycle and Fresh Water Supply

## Introduction

Water, air, and food are the most important natural resources to people. Humans can live only a few minutes without oxygen, about a week without water, and about a month without food. Water also is essential for our oxygen and food supply. Plants, which require water to survive, provide oxygen through photosynthesis and form the base of our food supply. Plants grow in soil, which forms by weathering reactions between water and rock (Theis & Tomkin, 2015).

Water is the most essential compound for Earth's life in general. Human babies are approximately 75% water and adults are 60% water. Our brain is about 85% water, blood and kidneys are 83% water, muscles are 76% water, and even bones are 22% water. We constantly lose water by perspiration; in temperate climates we should drink about 2 quarts of water per day and people in hot desert climates should drink up to 10 quarts of water per day. Loss of 15% of body-water usually causes death. Earth is truly the Water Planet. The abundance of water on Earth distinguishes us from other bodies in the solar system. About 70% of Earth's surface is covered by oceans and approximately half of Earth's surface is obscured by clouds at any time. There is a very large volume of water on our planet, about 1.4 billion cubic kilometers (km3) (330 million cubic miles) or about 53 billion gallons per person on Earth. All of Earth's water could cover the United States to a depth of 145 km (90 mi). From a human perspective, the problem is that over 97% of it is seawater, which is too salty to drink or use for irrigation. The most commonly used water sources are rivers and lakes, which contain less than 0.01% of the world's water!

One of our most important environmental goals is to provide a clean, sufficient, and sustainable water supply for the world. Fortunately, water is a renewable resource, and it is difficult to destroy. Evaporation and precipitation combine to replenish our fresh water supply constantly and quickly; however, water availability is complicated by its uneven distribution over the Earth. Arid climate and densely populated areas have combined in many parts of the world to create water shortages, which are projected to worsen in the coming years. Human activities such as water overuse and water pollution have compounded significantly the water crisis that exists today. Hundreds of millions of people lack access to safe drinking water, and billions of people lack access to improved sanitation as simple as a pit latrine. As a result, nearly two million people die every year from diarrheal diseases and 90% of those deaths occur among children under the age of 5. Most of these are easily prevented deaths.

## Water Reservoirs and Water Cycle

Water is the only substance that occurs naturally on earth in three forms: solid, liquid and gas. It is distributed in various locations, called water reservoirs. The oceans are by far the largest of the reservoirs with about 97% of all water but that water is too saline for most human uses (Figure 13.2). Ice caps and glaciers are the largest reservoirs of fresh water but this water is inconveniently located, mostly in Antarctica and Greenland. Shallow groundwater is the largest reservoir of usable fresh water. Although rivers and lakes are the most heavily used water resources, they represent only a tiny amount of the world's water. If all of world's water was shrunk to the size of 1 gallon, then the total amount of fresh water would be about 1/3 cup, and the amount of readily usable fresh water would be 2 tablespoons.

The water (or hydrologic) cycle (that we covered in Chapter "Ecosystems and the Biosphere") shows the movement of water through different reservoirs, which include oceans, atmosphere, glaciers, groundwater, lakes, rivers, and biosphere. Solar energy and gravity drive the motion of water in the water cycle. Simply put, the water cycle involves water moving from the ocean to the atmosphere by evaporation, forming clouds. From clouds, it falls as precipitation (rain and snow) on both water and land, where it can move in a variety of ways. The water on land can either return to the ocean by surface runoff (unchannelized overland overflow), rivers, glaciers, and subsur-

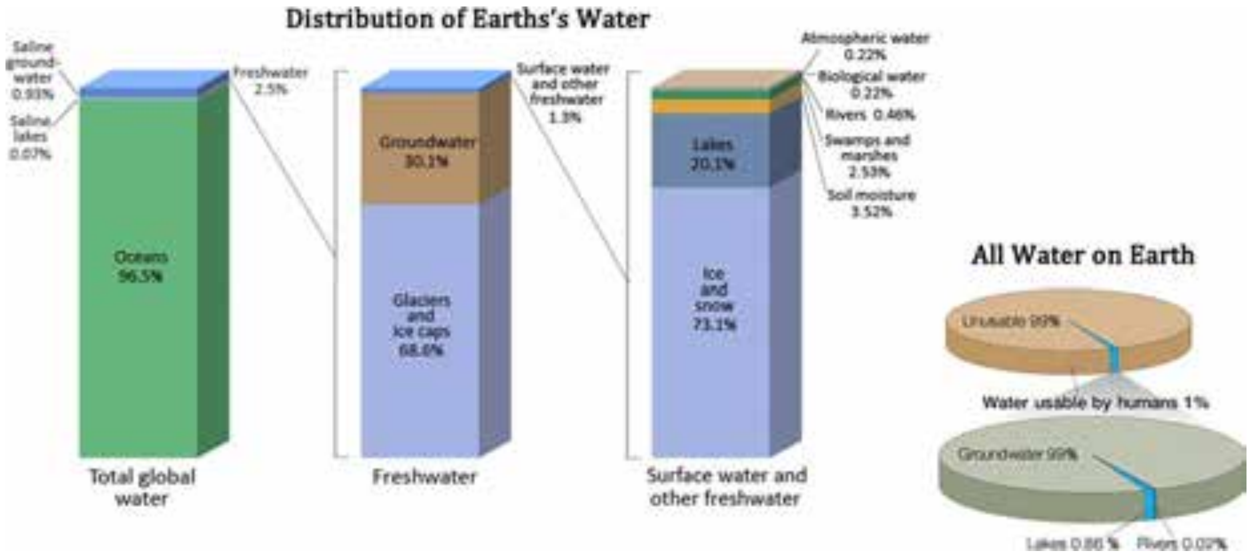


FIGURE 13.2

Earth's Water Reservoirs. Bar chart Distribution of Earth's water including total global water, fresh water, and surface water and other fresh water and Pie chart Water usable by humans and sources of usable water. Source: United States Geographical Survey Igor Skiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources

face groundwater flow, or return to the atmosphere by evaporation or transpiration (loss of water by plants to the atmosphere).

An important part of the water cycle is how water varies in salinity, which is the abundance of dissolved ions in water. Ocean water is called salt water because it is highly saline, with about 35,000 mg of dissolved ions per liter of seawater. Evaporation (where water changes from liquid to gas at ambient temperatures) is a distillation process that produces nearly pure water with almost no dissolved ions. As water vaporizes, it leaves the dissolved ions in the original liquid phase. Eventually, condensation (where water changes from gas to liquid) forms clouds and sometimes precipitation (rain and snow). After rainwater falls onto land, it dissolves minerals, which increases its salinity. Most lakes, rivers, and near-surface groundwater have a relatively low salinity and are called fresh water. The next several sections discuss important parts of the water cycle relative to fresh water resources.

### Primary Fresh Water Resources: Precipitation

Precipitation is a major control of fresh water availability, and it is unevenly distributed around the globe (see Figure 13.4). More precipitation falls near the equator, and landmasses there are characterized by a tropical rainforest climate. Less precipitation tends to fall near 2030 north and south latitude, where the world's largest deserts are located. These rainfall and climate patterns are related to global wind circulation cells. The intense sunlight at the equator heats air, causing it to rise and cool, which decreases the ability of the air mass to hold water vapor and results in frequent rainstorms. Around 30 degrees north and south latitude, descending air conditions produce warmer air, which increases its ability to hold water vapor and results in dry conditions. Both the dry air conditions and the warm temperatures of these latitude belts favor evaporation. Global precipitation and climate patterns are also affected by the size of continents, major ocean currents, and mountains.

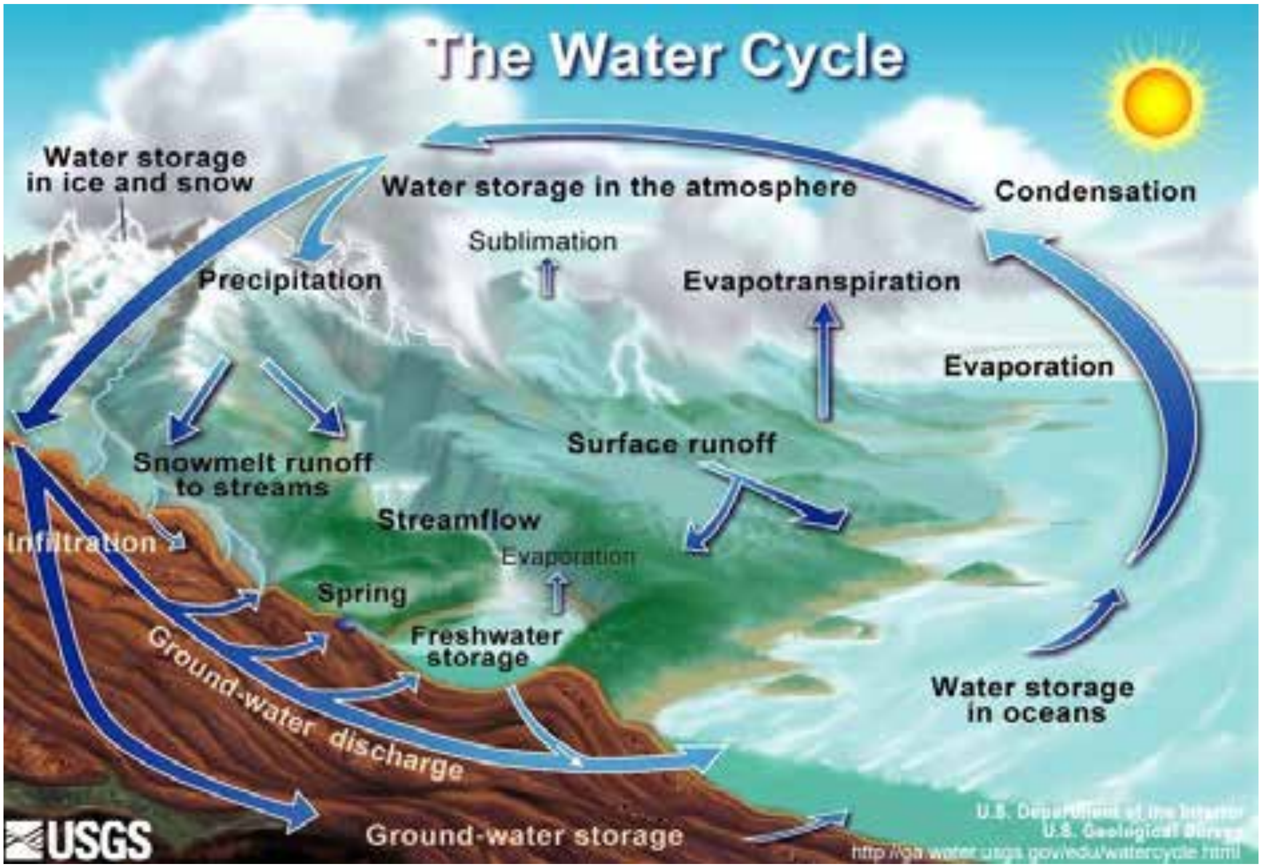


FIGURE 13.3

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

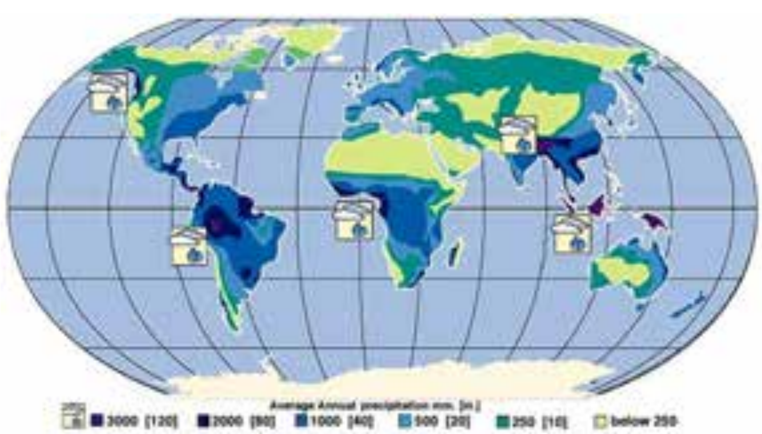


FIGURE 13.4

World Rainfall Map. The false-color map above shows the amount of rain that falls around the world. Areas of high rainfall include Central and South America, western Africa, and Southeast Asia. Since these areas receive so much rainfall, they are where most of the world's rainforests grow. Areas with very little rainfall usu- ally turn into deserts. The desert areas include North Africa, the Middle East, western North America, and Central Asia. Source: United States Geological Survey Earth Forum, Houston Museum Natural Science

### Surface Water Resources: Rivers, Lakes, Glaciers

Flowing water from rain and melted snow on land enters river channels by surface runoff (see Figure Surface Runoff (Figure 13.5) and groundwater seepage (see Figure Groundwater Seepage (Figure 13.6). River discharge describes the volume of water moving through a river channel over time (Figure 13.7). The relative contributions of surface runoff vs. groundwater seepage to river discharge depend on precipitation patterns, vegetation, topography, land use, and soil characteristics. Soon after a heavy rainstorm, river discharge increases due to surface runo. The steady normal ow of river water is mainly from groundwater that discharges into the river. Gravity pulls river water downhill toward the ocean. Along the way the moving water of a river can erode soil particles and dissolve minerals, creating the river's load of moving sediment grains and dissolved ions. Groundwater also contributes a large amount of the dissolved ions in river water. The geographic area drained by a river and its tributaries is called a drainage basin. The Mississippi River drainage basin includes approximately 40% of the U.S., a measure that includes the smaller drainage basins (also called watersheds), such as the Ohio River and Missouri River that help to comprise it. **Rivers** are an important water resource for irrigation and many cities around the world. Some of the world's rivers that have had international disputes over water supply include the Colorado (Mexico, southwest U.S.), Nile (Egypt, Ethiopia, Sudan), Euphrates (Iraq, Syria, Turkey), Ganges (Bangladesh, India), and Jordan (Israel, Jordan, Syria).

**Lakes** can also be an excellent source of fresh water for human use. They usually receive water from surface runoff and groundwater discharge. They tend to be short-lived on a geological time-scale because they are constantly filling in with sediment supplied by rivers. Lakes form in a variety of ways including glaciation, recent tectonic uplift (Lake Tanganyika, Africa), and volcanic eruptions (Crater Lake, Oregon). People also create artificial lakes (reservoirs) by damming rivers. Large changes in climate can result in major changes in a lake's size. As Earth was coming out of the last Ice Age about fifteen thousand years ago, the climate in the western U.S. changed from cool and moist to warm and arid, which caused more than 100 large lakes to disappear. The Great Salt Lake in Utah is a remnant of a much larger lake called Lake Bonneville.

Although **glaciers** represent the largest reservoir of fresh water, they generally are not used as a water source because they are located too far from most people (see Figure 13.8). Melting glaciers do provide a natural source of river water and groundwater. During the last Ice Age there was as much as 50% more water in glaciers than there is today, which caused sea level to be about 100 m lower. Over the past century, sea level has been rising in part due to melting glaciers. If Earth's climate continues to warm, the melting glaciers will cause an additional rise in sea level.

### Groundwater Resources

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

Other sources of groundwater include seepage from surface water (lakes, rivers, reservoirs, and swamps), surface water deliberately pumped into the ground, irrigation, and underground wastewater treatment systems, i.e., septic tanks. *Recharge areas* are locations where surface water infiltrates the ground rather than running o into rivers or evaporating. *Wetlands* and at vegetated areas in general are excellent recharge areas.

An earth material that is capable of supplying groundwater from a well at a useful rate (has relatively high permeability and medium to high porosity) is called an **aquifer**. To find a large aquifer for a city, **hydrogeologists** (geologists who specialize in groundwater) use a variety of information including knowledge of earth materials at the surface and sub-surface as well as test wells. Groundwater and surface water (rivers, lakes, swamps, and reservoirs) are strongly interrelated because both are part of the same overall resource.

FIGURE 13.5

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

## Water Use in the U.S. and World

People need water to produce the food, energy, and mineral resources they use–commonly large amounts of it (Theis & Tomkin, 2015). Consider, for example, these approximate water requirements for some things people in the developed world use every day: one tomato = 3 gallons; one kilowatt-hour of electricity (from a thermoelectric power plant) = 21 gallons; one loaf of bread = 150 gallons; one pound of beef = 1,600 gallons; and one ton of steel = 63,000 gallons. Human beings require only about 1 gallon per day to survive, but a typical person in a U.S. household uses approximately 100 gallons per day, which includes cooking, washing dishes and clothes, flushing the toilet, and bathing.

The **water demand** of an area is a function of the population and other uses of water. There are several general categories of water use, including *offstream use*, which removes water from its source, e.g., irrigation, thermoelectric power generation (cooling electricity-producing equipment in fossil fuel, nuclear, and geothermal power plants), industry, and public supply; consumptive use , which is a type of off-stream use where water does not return to the surface water or groundwater system immediately after use, e.g., irrigation water that evaporates or goes to plant growth; and instream use, which is water used but not removed from a river, mostly for hydroelectric power generation. The relative size of these three categories are instream use offstream use > consumptive use. In

FIGURE 13.6
Groundwater Seepage. Groundwater seepage can be seen in Box Canyon in Idaho, where approximately 10 cubic meters per second of seepage emanates from its vertical headwall. Source: NASA

FIGURE 13.7
River Discharge Colorado River, U.S.. Rivers are part of overland flow in the water cycle and an important surface water resource. Source: Gonzo fan2007 at Wikimedia Commons

2005, the U.S. used approximately 3,300 billion gallons per day for instream use, 410 billion gallons per day for offstream use, and 100 billion gallons per day for consumptive use. The major offstream uses of that water were thermoelectric (49%), irrigation (31%), public supply (11%), and industry. About 15% of the total water withdrawals in the U.S. in 2005 were saline water, which was used almost entirely for thermoelectric power generation. Almost all of the water used for thermoelectric power generation is returned to the river, lake, or ocean from where it came but about half of irrigation water does not return to the original source due to evaporation, plant transpiration, and loss during transport, e.g., leaking pipes. Total withdrawals of water in the U.S. actually decreased slightly from 1980 to 2005, despite a steadily increasing population.This is because the two largest categories of water use (thermoelectric and irrigation) stabilized or decreased over that time period due to better water management and conservation. In contrast, public supply water demand increased steadily from 1950 (when estimates began) through 2005. Approximately 77% of the water for offstream use in the U.S. in 2005 came from surface water and the rest was from groundwater.

In contrast to trends in the U.S., global total water use is steadily increasing at a rate greater than world population

FIGURE 13.8

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

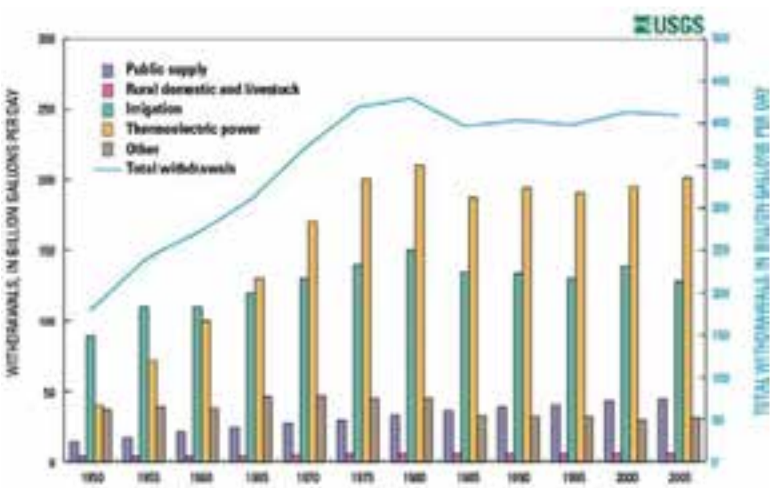


FIGURE 13.9

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

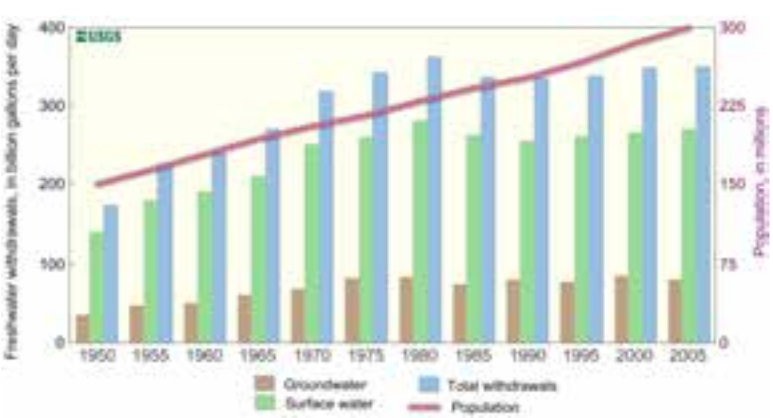


FIGURE 13.10

Trends in Source of Fresh Water Withdrawals in the U.S. from 1950 to 2005 Trends in source of fresh water withdrawals in the U.S. from 1950 to 2005, including bars for surface water, ground- water, and total water. Red line gives U.S. population using vertical scale on right. Source: United States Geological Survey growth (see Figure 13.11). During the twentieth century global population tripled and water demand grew by a factor of six. The increase in global water demand beyond the rate of population growth is due to improved standard of living without an offset by water conservation. Increased production of goods and energy entails a large increase in water demand. The major global offstream water uses are irrigation (68%), public supply (21%), and industry (11%).

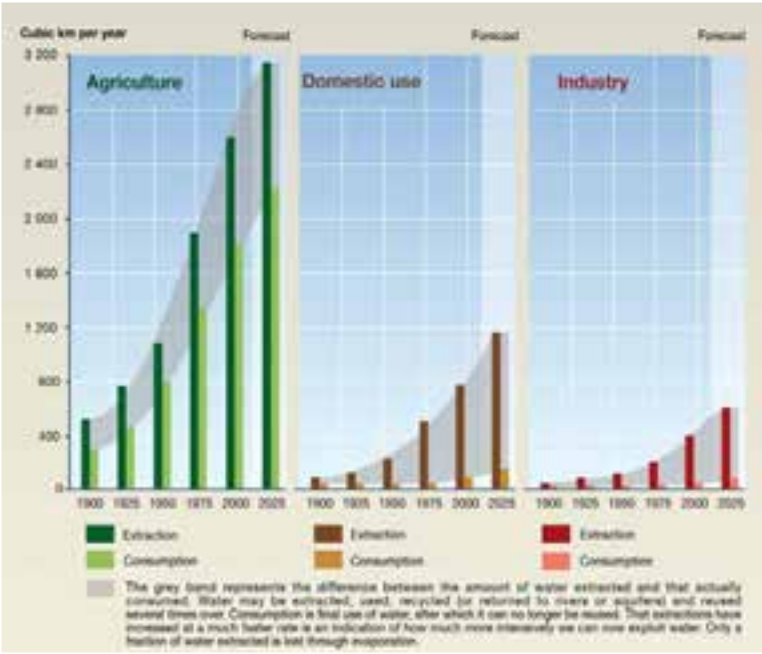


FIGURE 13.11

Trends in World Water Use from 1900 to 2000 and Projected to 2025 For each water major use category, including trends for agriculture, domestic use, and industry. Darker colored bar represents total water extracted for that use category and lighter colored bar represents water consumed (i.e., water that is not quickly returned to surface water or groundwater system) for that use category. Source: Igor A. Shiklomanow, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UN- ESCO, Paris), 1999

# 13.2 Water Supply Problems and Solutions

### Water Supply Problems: Resource Depletion

As groundwater is pumped from water wells, there usually is a localized drop in the water table around the well called a cone of depression (Theis & Tomkin, 2015). When there are a large number of wells that have been pumping water for a long time, the regional water table can drop significantly. This is called **groundwater mining**, which can force the drilling of deeper, more expensive wells that commonly encounter more saline groundwater. Rivers, lakes, and artificial lakes (reservoirs) can also be depleted due to overuse. Some large rivers, such as the Colorado in the U.S. and Yellow in China, run dry in some years. The case history of the Aral Sea discussed in this chapter involves depletion of a lake. Finally, glaciers are being depleted due to accelerated melting associated with global warming over the past century.

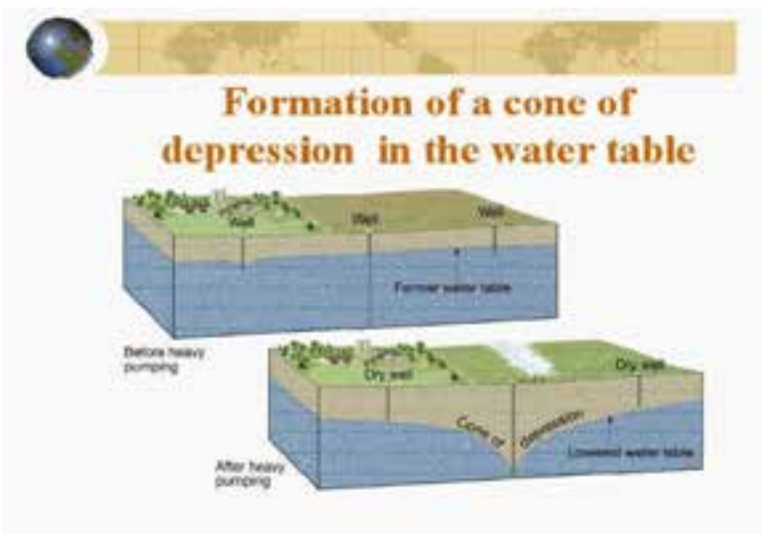


FIGURE 13.12

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

Another water resource problem associated with groundwater mining is saltwater intrusion, where overpumping of fresh water aquifers near ocean coastlines causes saltwater to enter fresh water zones. The drop of the water table around a **cone of depression** in an unconfined aquifer can change the regional groundwater ow direction, which could send nearby pollution toward the pumping well instead of away from it. Finally, problems of subsidence (gradual sinking of the land surface over a large area) and sinkholes (rapid sinking of the land surface over a small area) can develop due to a drop in the water table.

### Water Supply Crisis

The **water crisis** refers to a global situation where people in many areas lack access to sufficient water or clean water or both. This section describes the global situation involving water shortages, also called water stress. The next section covers the water crisis involving water pollution. Due to population growth the 2025 projection for global water stress is significantly worse than water stress levels in 1995. In general, water stress is greatest in areas with very low precipitation (major deserts) or large population density (e.g., India) or both. Future global warming could worsen the water crisis by shifting precipitation patterns away from humid areas and by melting mountain glaciers that recharge rivers downstream. Melting glaciers will also contribute to rising sea level, which will worsen saltwater intrusion in aquifers near ocean coastlines. Compounding the water crisis is the issue of social injustice; poor people generally get less access to clean water and commonly pay more for water than wealthy people.


FIGURE 13.13

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

According to a 2006 report by the United Nations Development Programme, in 2005, 700 million people (11% of the world's population) lived under water stress with a per capita water supply below 1,700 m3/year25 . Most of them live in the Middle East and North Africa. By 2025, the report projects that more than 3 billion people (about 40% of the world's population) will live in water-stressed areas with the large increase coming mainly from China and India. The water crisis will also impact food production and our ability to feed the ever-growing population. We can expect future global tension and even conflict associated with water shortages and pollution. Historic and future areas of water conflict include the Middle East (Euphrates and Tigris River conflict among Turkey, Syria, and Iraq; Jordan River conflict among Israel, Lebanon, Jordan, and the Palestinian territories), Africa (Nile River conflict among Egypt, Ethiopia, and Sudan), Central Asia (Aral Sea conflict among Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan), and south Asia (Ganges River conflict between India and Pakistan).

### Sustainable Solutions to the Water Supply Crisis?

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

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

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

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

FIGURE 13.14

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

FIGURE 13.15

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

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

**Rainwater harvesting** involves catching and storing rainwater for reuse before it reaches the ground. Efficient irrigation is extremely important because irrigation accounts for a much larger water demand than public water supply. Water conservation strategies in agriculture include growing crops in areas where the natural rainfall can support them, more efficient irrigation systems such as drip systems that minimize losses due to evaporation, no- till farming that reduces evaporative losses by covering the soil, and reusing treated wastewater from sewage treatment plants. Recycled wastewater has also been used to recharge aquifers. There are a great many other specific water conservation strategies. Sustainable solutions to the water crisis must use a variety of approaches but they should have water conservation as a high priority.

## 13.3 Water Pollution

The Module Water Cycle and Freshwater Supply described one aspect of the global water crisis, the water shortages that afflict many arid and densely populated areas (Theis & Tomkin, 2015). The global water crisis also involves water pollution, because to be useful for drinking and irrigation, water must not be polluted beyond certain thresholds. According to the World Health Organization, in 2008 approximately 880 million people in the world (or 13% of world population) did not have access to improved (safe) drinking water. At the same time, about 2.6 billion people (or 40% of world population) lived without improved sanitation, which is defined as having access to a public sewage system, septic tank, or even a simple pit latrine. Each year approximately 1.7 million people die from diarrheal diseases associated with unsafe drinking water, inadequate sanitation, and poor hygiene, e.g., hand washing with soap. Almost all of these deaths are in developing countries, and around 90% of them occur among children under the age of 5 (see Figure 13.16). Compounding the water crisis is the issue of social justice; poor people more commonly lack clean water and sanitation than wealthy people in similar areas. Globally, improving water, sanitation, and hygiene could prevent up to 9% of all disease and 6% of all deaths. In addition to the global waterborne disease crisis, chemical pollution from agriculture, industry, cities, and mining threatens global water quality. Some chemical pollutants have serious and well-known health effects; however, many others have poorly known long-term health effects. In the U.S. currently more than 40,000 water bodies fit the definition of "impaired" set by EPA, which means they could neither support a healthy ecosystem nor meet water quality standards. In Gallup public polls conducted over the past decade Americans consistently put water pollution and water supply as the top environmental concerns over issues such as air pollution, deforestation, species extinction, and global warming.

Any natural water contains dissolved chemicals; some of these are important human nutrients, while others can be harmful to human health. The abundance of a water pollutant is commonly given in very small concentration units such as parts per million (ppm) or even parts per billion (ppb). An arsenic concentration of 1 ppm means 1 part of arsenic per million parts of water. This is equivalent to one drop of arsenic in 50 liters of water. To give you a different perspective on appreciating small concentration units, converting 1 ppm to length units is 1 cm (0.4 in) in 10 km (6 miles) and converting 1 ppm to time units is 30 seconds in a year. Total dissolved solids (TDS) represent the total amount of dissolved material in water. Average TDS (salinity) values for rainwater, river water, and seawater are about 4 ppm, 120 ppm, and 35,000 ppm. Fresh water is commonly defined as containing less than either 1,000 or 500 ppm TDS, but the US Environmental Protection Agency (EPA) recommends that drinking water not exceed 500 ppm TDS or else it will have an unpleasant salty taste.

Water Pollution Overview

Water pollution is the contamination of water by an excess amount of a substance that can cause harm to human beings and the ecosystem. The level of water pollution depends on the abundance of the pollutant, the ecological impact of the pollutant, and the use of the water. Pollutants are derived from biological, chemical, or physical processes. Although natural processes such as volcanic eruptions or evaporation sometimes can cause water pollution, most pollution is derived from human, land-based activities (see Figure 13.17). Water pollutants can move through different water reservoirs, as the water carrying them progresses through stages of the water cycle (see Figure 13.18). Water residence time (the average time that a water molecule spends in a water reservoir) is very important to pollution problems because it affects pollution potential. Water in rivers has a relatively short residence time, so pollution usually is there only briefly. Of course, pollution in rivers may simply move to another reservoir, such as the ocean, where it can cause further problems. Groundwater is typically characterized by slow flow and longer residence time, which can make groundwater pollution particularly problematic. Finally, pollution residence time can be much greater than the water residence time because a pollutant may be taken up for a long time within the ecosystem or absorbed onto sediment.

Pollutants enter water supplies from point sources, which are readily identifiable and relatively small locations, or nonpoint sources, which are large and more diffuse areas. **Point sources** of pollution include animal "factory"

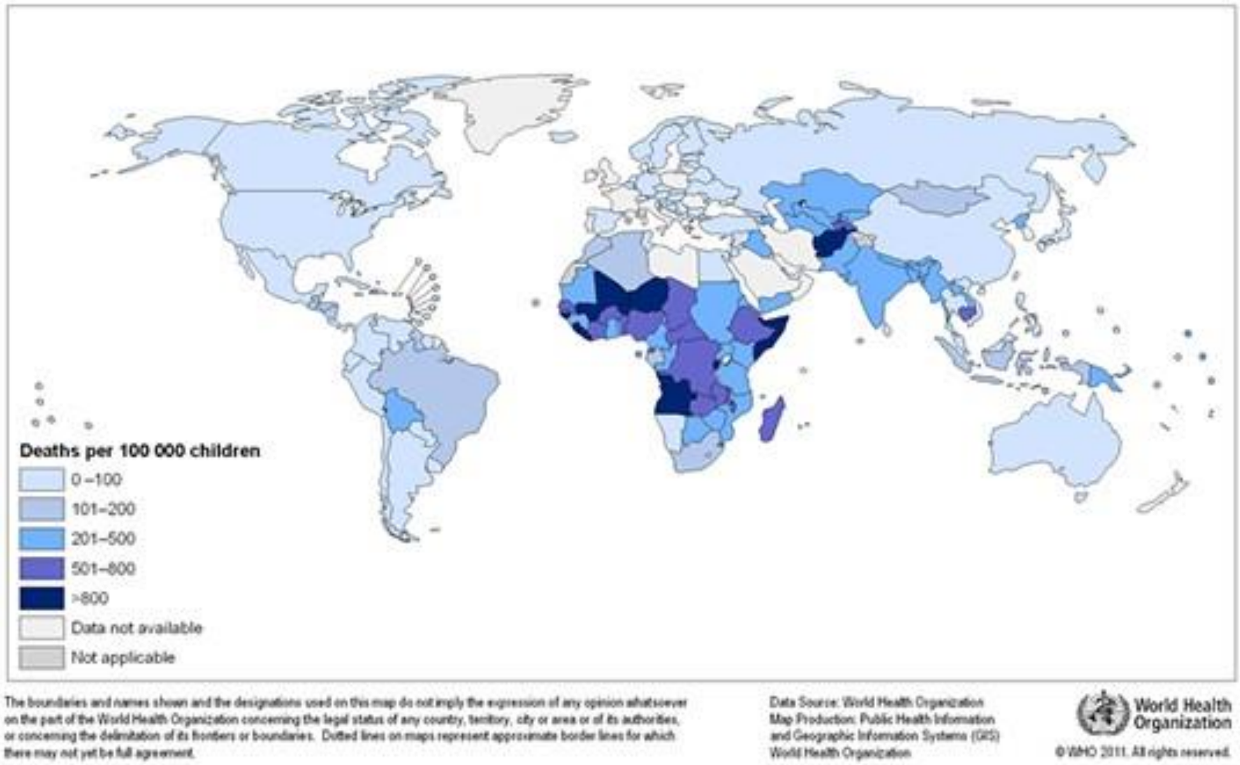


FIGURE 13.16

Deaths by Country from Diarrhea Caused by Unsafe Water, Unimproved Sanitation, and Poor Hygiene in Children. Less than 5 Years Old, 2004 Source: World Health Organization

farms that raise a large number and high density of livestock such as cows, pigs, and chickens and discharge pipes from a factories or sewage treatment plants. Combined sewer systems that have a single set of underground pipes to collect both sewage and storm water runoff from streets for wastewater treatment can be major point sources of pollutants. During heavy rain, storm water runoff may exceed sewer capacity, causing it to back up and spilling untreated sewage into surface waters. Nonpoint sources of pollution include agricultural fields, cities, and abandoned mines. Rainfall runs over the land and through the ground, picking up pollutants such as herbicides, pesticides, and fertilizer from agricultural fields and lawns; oil, antifreeze, car detergent, animal waste, and road salt from urban areas; and acid and toxic elements from abandoned mines. Then, this pollution is carried into surface water bodies and groundwater. **Nonpoint source pollution**, which is the leading cause of water pollution in the U.S., is usually much more difficult and expensive to control than point source pollution because of its low concentration, multiple sources, and much greater volume of water.

FIGURE 13.17

Water Pollution Obvious water pollution in the form of floating debris; invisible water pollutants sometimes can be much more harmful than visible ones. Source: Stephen Codrington at Wikimedia Commons

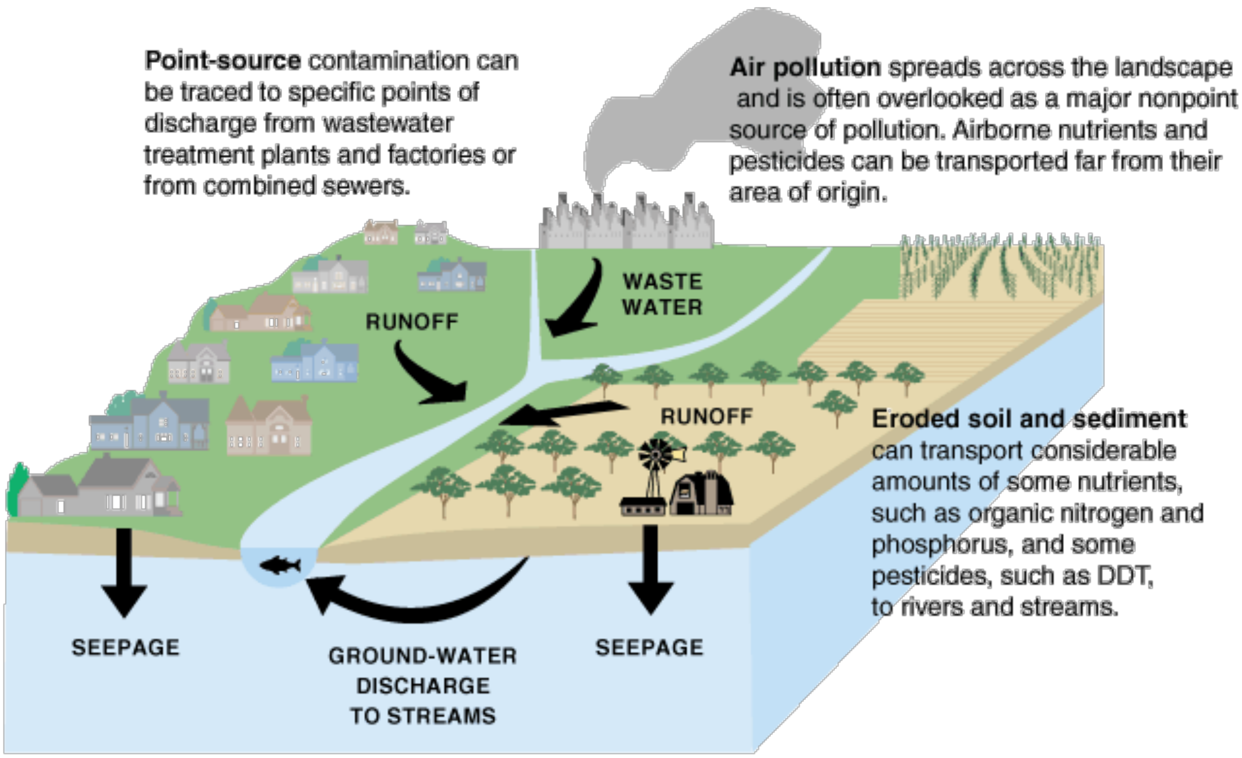


FIGURE 13.18

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

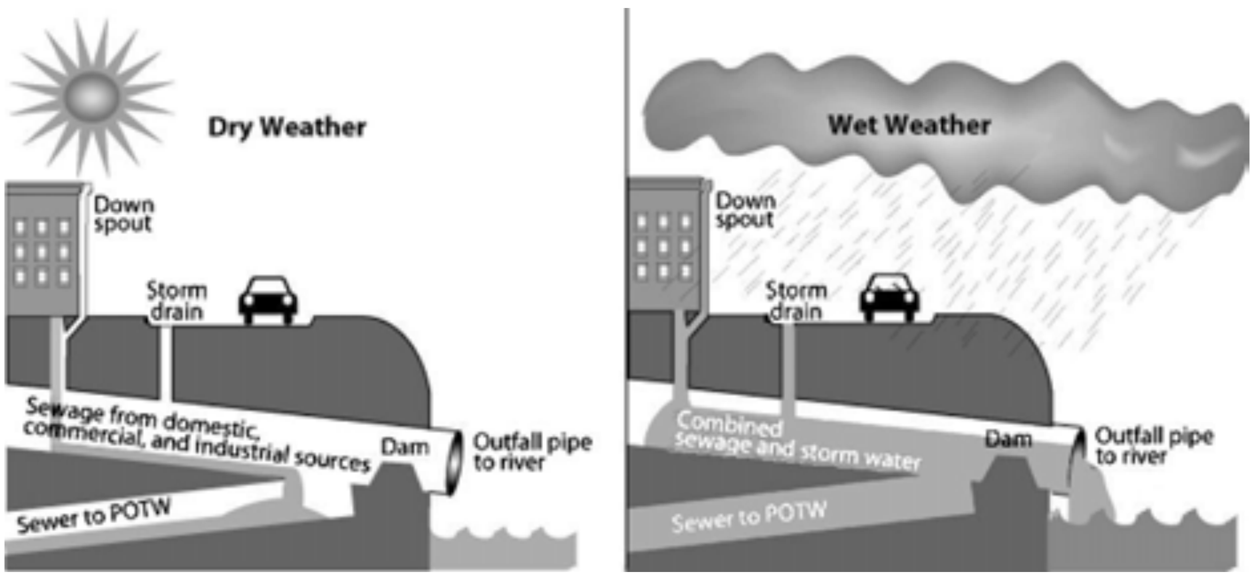


FIGURE 13.19

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

## Types of Water Pollutants

Oxygen-demanding waste is an extremely important pollutant to ecosystems. Most surface water in contact with the atmosphere has a small amount of dissolved oxygen, which is needed by aquatic organisms for cellular respiration. Bacteria decompose dead organic matter (chemically represented in a simplified way as $CH_2O$) and remove dissolved oxygen ($O_2$) according to the following reaction:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O$$

Too much decaying organic matter in water is a pollutant because it removes oxygen from water, which can kill fish, shellfish, and aquatic insects. The amount of oxygen used by aerobic (in the presence of oxygen) bacterial decomposition of organic matter is called biochemical oxygen demand (BOD). The major source of dead organic matter in most natural waters is sewage; grass and leaves are smaller sources. An unpolluted water body with respect to oxygen is a turbulent river that flows through a natural forest. Turbulence continually brings water in contact with the atmosphere where the $O_2$ content is restored. The dissolved oxygen content in such a river ranges from 10 to 14 ppm $O_2$, BOD is low, and clean-water fish, e.g., bass, trout, and perch dominate. A polluted water body with respect to oxygen is a stagnant deep lake in an urban setting with a combined sewer system. This system favors a high input of dead organic carbon from sewage overflows and limited chance for water circulation and contact with the atmosphere. In such a lake, the dissolved $O_2$ content is ≤5 ppm $O_2$, BOD is high, and low $O_2$-tolerant fish, e.g., carp and catfish dominate.

Excessive plant nutrients, particularly nitrogen (N) and phosphorous (P), are pollutants closely related to oxygen-demanding waste. Aquatic plants require about 15 nutrients for growth, most of which are plentiful in water. N and P are called *limiting nutrients*, because they usually are present in water at low concentrations and therefore restrict the total amount of plant growth. This explains why N and P are major ingredients in most fertilizer. High concentrations of N and P from human sources (mostly agricultural and urban runoff including fertilizer, sewage, and P-based detergent) can cause cultural eutrophication, which involves the rapid growth of aquatic plants, particularly algae, called an *algal bloom*. Thick mats of floating and rooted green or sometimes red algae create water pollution, damage the ecosystem by clogging fish gills and blocking sunlight, and damage lake aesthetics by making recreation difficult and creating an eyesore. A small percentage of algal species produce toxins that can kill fish, mammals, and birds, and may cause human illness; explosive growths of these algae are called *harmful algal blooms*. When the prolific algal layer dies, it becomes oxygen-demanding waste, which can create very low $O_2$ water ($<\sim 2$ ppm $O_2$), called hypoxia or dead zone because it causes death to organisms that are unable to leave that environment. An estimated 50% of lakes in North America, Europe, and Asia are negatively impacted by cultural eutrophication. In addition, the size and number of marine hypoxic zones have grown dramatically over the past 50 years including a very large dead zone located offshore Louisiana in the Gulf of Mexico. Cultural eutrophication and hypoxia are difficult to combat, because they are caused primarily by nonpoint source pollution, which is difficult to regulate, and N and P, which are difficult to remove from wastewater.

**Pathogens** are disease-causing microorganisms, e.g., viruses, bacteria, parasitic worms, and protozoa, which cause a variety of intestinal diseases such as dysentery, typhoid fever, hepatitis, and cholera. Pathogens are the major cause of the water pollution crisis discussed at the beginning of this section. Unfortunately nearly a billion people around the world are exposed to waterborne pathogen pollution daily and around 1.5 million children mainly in underdeveloped countries die every year of waterborne diseases from pathogens. Pathogens enter water primarily from human and animal fecal waste due to inadequate sewage treatment. In many underdeveloped countries, sewage is discharged into local waters either untreated or after only rudimentary treatment. In developed countries untreated sewage discharge can occur from overflows of combined sewer systems, poorly managed livestock factory farms, and leaky or broken sewage collection systems. Water with pathogens can be remediated by adding chlorine or ozone, by boiling, or by treating the sewage in the first place.

**Oil spills** are another kind of organic pollution. Oil spills can result from supertanker accidents such as the Exxon Valdez in 1989, which spilled 10 million gallons of oil into the rich ecosystem of offshore south Alaska and killed massive numbers of animals. The largest marine oil spill was the Deepwater Horizon disaster, which began with a natural gas explosion (see Figure 13.20) at an oil well 65 km offshore of Louisiana and flowed for 3 months in 2010, releasing an estimated 200 million gallons of oil. The worst oil spill ever occurred during the Persian Gulf war of 1991, when Iraq deliberately dumped approximately 200 million gallons of oil in offshore Kuwait and set more than 700 oil well fires that released enormous clouds of smoke and acid rain for over nine months. During an oil spill on water, oil floats to the surface because it is less dense than water, and the lightest hydrocarbons evaporate, decreasing the size of the spill but polluting the air. Then, bacteria begin to decompose the remaining oil, in a process that can take many years. After several months only about 15% of the original volume may remain, but it is in thick asphalt lumps, a form that is particularly harmful to birds, fish, and shellfish. Cleanup operations can include skimmer ships that vacuum oil from the water surface (effective only for small spills), controlled burning (works only in early stages before the light, ignitable part evaporates but also pollutes the air), dispersants (detergents that break up oil to accelerate its decomposition, but some dispersants may be toxic to the ecosystem), and bioremediation (adding microorganisms that specialize in quickly decomposing oil, but this can disrupt the natural ecosystem).

FIGURE 13.20

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

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

Arsenic and mercury are discussed in more detail below.

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

Mercury (Hg) is used in a variety of electrical products, such as dry cell batteries, fluorescent light bulbs, and switches, as well as in the manufacture of paint, paper, vinyl chloride, and fungicides. As discussed in the Module "Environmental Toxicology", mercury concentrates in the food chain, especially in fish, in a process of biomagnification (see Figure 13.21). It acts on the central nervous system and can cause loss of sight, feeling, and hearing as well as nervousness, shakiness, and death. Like arsenic, mercury enters the water supply naturally from weathering of Hg-rich minerals and from human activities such as coal burning and metal processing. A famous mercury poisoning case in Minamata, Japan involved methylmercury-rich industrial discharge that caused high Hg levels in fish. People in the local fishing villages ate fish up to three times per day for over 30 years, which resulted in over 2,000 deaths. During that time the responsible company and national government did little to mitigate, help alleviate, or even acknowledge the problem.

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

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

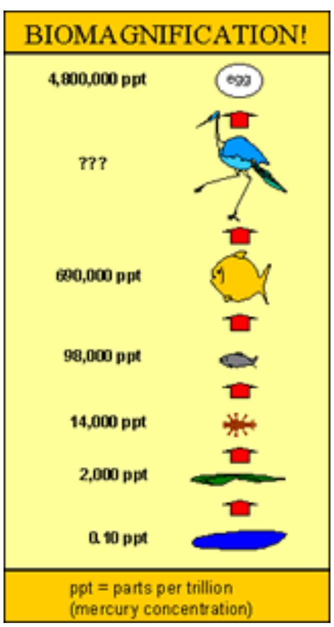


FIGURE 13.21

Biomagnification An illustrative example of biomagnification of mercury from water through the food chain and into a bird's egg. Source: U.S. Geological Survey.

## 13.4 Sustainable Solutions to the Water Pollution Crisis?

Resolution of the global water pollution crisis described at the beginning of this section requires multiple approaches to improve the quality of our fresh water and move towards sustainability (Theis & Tomkin, 2015). The most deadly form of water pollution, pathogenic microorganisms that cause waterborne diseases, kills almost 2 million people in underdeveloped countries every year. The best strategy for addressing this problem is proper sewage (wastewater) treatment. Untreated sewage is not only a major cause of pathogenic diseases, but also a major source of other pollutants, including oxygen-demanding waste, plant nutrients (N and P), and toxic heavy metals. Wastewater treatment is done at a sewage treatment plant in urban areas and through a septic tank system in rural areas.

The main purpose of a sewage treatment plant is to remove organic matter (oxygen-demanding waste) and kill bacteria; special methods also can be used to remove plant nutrients and other pollutants. The numerous processing steps at a conventional sewage treatment plant (see Figure 13.22) include *pretreatment* (screening and removal of sand and gravel), *primary treatment* (settling or floatation to remove organic solids, fat, and grease), *secondary treat- ment* (aerobic bacterial decomposition of organic solids), *tertiary treatment* (bacterial decomposition of nutrients and filtration), *disinfection* (treatment with chlorine, ozone, ultraviolet light, or bleach), and either *discharge* to surface waters (usually a local river) or *reuse* for some other purpose, such as irrigation, habitat preservation, and artificial groundwater recharge. The concentrated organic solid produced during primary and secondary treatment is called sludge, which is treated in a variety of ways including landfill disposal, incineration, use as fertilizer, and anaerobic bacterial decomposition, which is done in the absence of oxygen. Anaerobic decomposition of sludge produces methane gas, which can be used as an energy source. To reduce water pollution problems, separate sewer systems (where street runoff goes to rivers and only wastewater goes to a wastewater treatment plant) are much better than combined sewer systems, which can overflow and release untreated sewage into surface waters during heavy rain. Some cities such as Chicago, Illinois have constructed large underground caverns and also use abandoned rock quarries to hold storm sewer overflow. After the rain stops, the stored water goes to the sewage treatment plant for processing.

A septic tank system is an individual sewage treatment system for homes in rural and even some urban settings. The basic components of a septic tank system (see Figure 13.23) include a sewer line from the house, a *septic tank* (a large container where sludge settles to the bottom and microorganisms decompose the organic solids anaerobically), and the drain field (network of perforated pipes where the clarified water seeps into the soil and is further purified by bacteria). Water pollution problems occur if the septic tank malfunctions, which usually occurs when a system is established in the wrong type of soil or maintained poorly.

For many developing countries, financial aid is necessary to build adequate sewage treatment facilities; however, the World Health Organization estimates an estimated cost savings of between $3 and $34 for every $1 invested in clean water delivery and sanitation. The cost savings are from health care savings, gains in work and school productivity, and deaths prevented. Simple and inexpensive techniques for treating water at home include chlorination, filters, and solar disinfection. Another alternative is to use constructed wetlands technology (marshes built to treat contaminated water), which is simpler and cheaper than a conventional sewage treatment plant.

**Bottled water** is not a sustainable solution to the water crisis, despite exponential growth in popularity in the U.S. and the world. Bottled water is not necessarily any safer than the U.S. public water supply, it costs on average about 700 times more than U.S. tap water, and every year it uses approximately 200 billion plastic and glass bottles that have a relatively low rate of recycling. Compared to tap water, it uses much more energy, mainly in bottle manufacturing and long-distance transportation. If you don't like the taste of your tap water, then please use a water filter instead of bottled water!

Additional sustainable solutions to the water pollution crisis include legislation to eliminate or greatly reduce point sources of water pollution. In the U.S., the Clean Water Act of 1972 and later amendments led to major

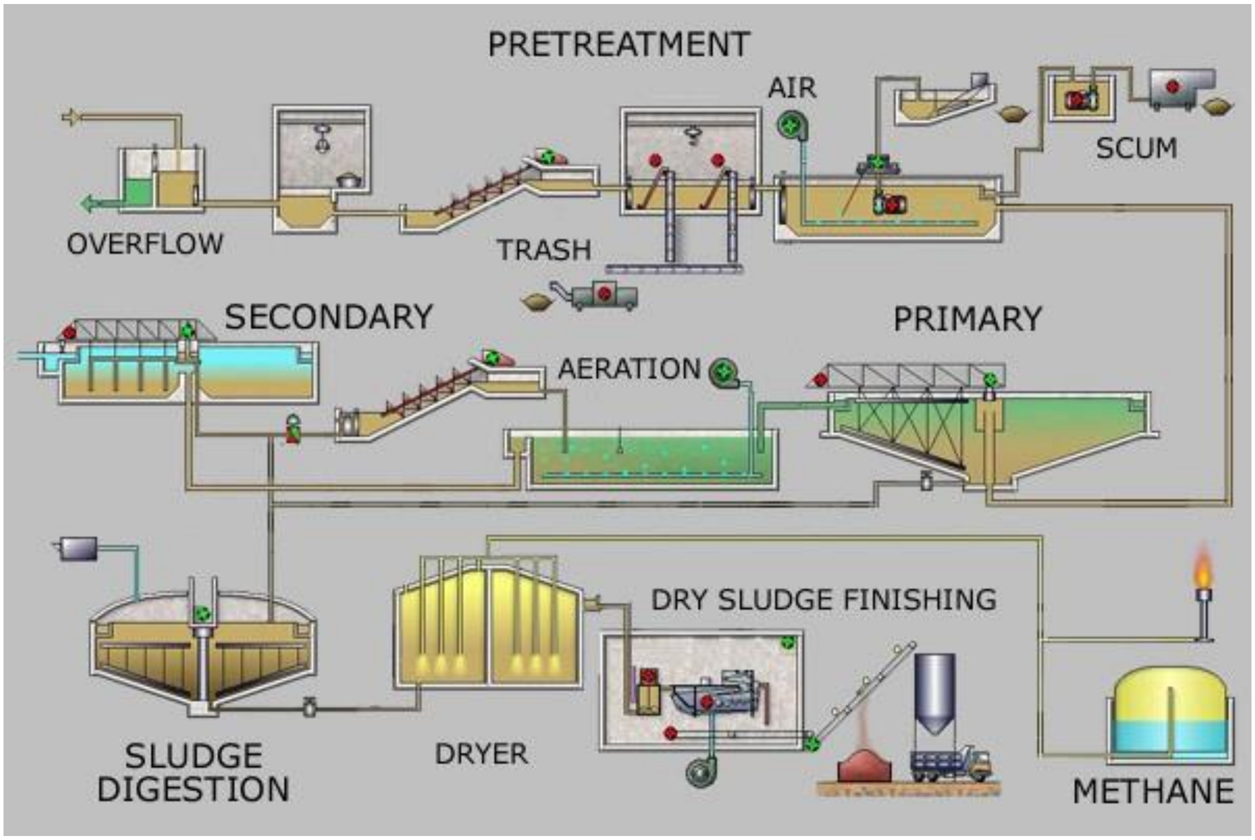


FIGURE 13.22

Steps at a Sewage Treatment Plant The numerous processing steps at a conventional sewage treatment plant include pretreatment (screening and removal of sand and gravel), primary treatment (settling or floatation to remove organic solids, fat, and grease), secondary treatment (aerobic bacterial decomposition of organic solids), tertiary treatment (bacterial decomposition of nutrients and filtration), disinfection (treatment with chlorine, ozone, ultraviolet light, or bleach), and either discharge to surface waters (usually a local river) or reuse for some other purpose, such as irrigation, habitat preservation, and artificial groundwater recharge.

Leonard, G. (2006). ESQUEMPEQUE-EN. (JPG). Retrieved from https://en.wikipedia.org/wiki/File:ESQUEMPEQUE-EN.jpg.

improvements in water quality. Nonpoint sources of water pollution, e.g., agricultural runoff and urban runoff are much harder to regulate because of their widespread, diffuse nature. There are many construction and agricultural practices that reduce polluted runoff including no-till farming and sediment traps. Artificial aeration or mechanical mixing can remediate lakes with oxygen depletion. Specific things that we can do to reduce urban runoff include the following: keep soil, leaves, and grass clippings off driveways, sidewalks, and streets; don't pour used motor oil, antifreeze, paints, pesticides, or any household hazardous chemical down the storm sewer or drain; recycle used motor oil; use hazardous waste disposal programs offered by the community; compost your organic waste; don't use fertilizers and herbicides on your lawn; and flush pet waste down the toilet.

Sometimes slow flow through a soil can naturally purify groundwater because some pollutants, such as P, pesticides, and heavy metals, chemically bind with surfaces of soil clays and iron oxides. Other pollutants are not retained by soil particles: These include N, road salt, gasoline fuel, the herbicide atrazine, tetrachloroethylene (a carcinogenic cleaning solvent used in dry cleaning), and vinyl chloride. In other cases, slow groundwater flow can allow bacteria to decompose dead organic matter and certain pesticides. There are many other ways to remediate polluted

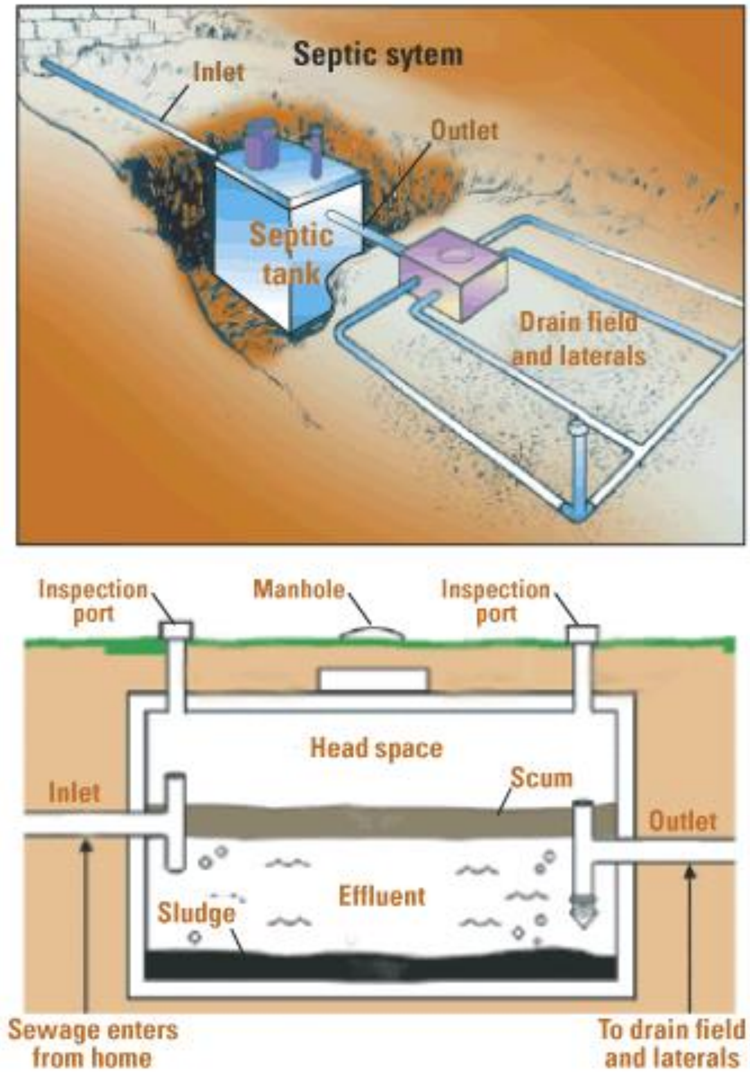


FIGURE 13.23

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

groundwater. Sometimes the best solution is to stop the pollution source and allow natural cleanup. Specific treatment methods depend on the geology, hydrology, and pollutant because some light contaminants flow on top of groundwater, others dissolve and flow with groundwater, and dense contaminants can sink below groundwater. A common cleanup method called pump and treat involves pumping out the contaminated groundwater and treating it by oxidation, filtration, or biological methods. Sometimes soil must be excavated and sent to a landfill. In-situ treatment methods include adding chemicals to immobilize heavy metals, creating a permeable reaction zone with metallic iron that can destroy organic solvents, or using bioremediation by adding oxygen or nutrients to stimulate growth of microorganisms.

## CLEAN WATER ACT

During the early 1900s rapid industrialization in the U.S. resulted in widespread water pollution due to free discharge of waste into surface waters. The Cuyahoga River in northeast Ohio caught fire numerous times, including a famous fire in 1969 that caught the nation's attention. In 1972 Congress passed one of the most important environmental laws in U.S. history, the Federal Water Pollution Control Act, which is more commonly called the Clean Water Act. The purpose of the Clean Water Act and later amendments is to maintain and restore water quality, or in simpler terms to make our water swimmable and fishable. It became illegal to dump pollution into surface water unless there was formal permission and U.S. water quality improved significantly as a result. More progress is needed because currently the EPA considers over 40,000 U.S. water bodies as impaired, most commonly due to pathogens, metals, plant nutrients, and oxygen depletion. Another concern is protecting groundwater quality, which is not yet addressed sufficiently by federal law.

## 13.4 Case Study: The Aral Sea - Going, Going, Gone

The Aral Sea is a lake located east of the Caspian Sea between Uzbekistan and Kazakhstan in central Asia (Theis & Tomkin, 2015). This area is part of the Turkestan desert, which is the fourth largest desert in the world; it is produced from a rain shadow effect by Afghanistan's high mountains to the south. Due to the arid and seasonally hot climate there is extensive evaporation and limited surface waters in general. Summer temperatures can reach 60$^o$C (140$^o$F)! The water supply to the Aral Sea is mainly from two rivers, the Amu Darya and Syr Darya, which carry snowmelt from mountainous areas. In the early 1960s the then-Soviet Union diverted the Amu Darya and Syr Darya Rivers for irrigation of one of the driest parts of Asia to produce rice, melons, cereals, and especially cotton. The Soviets wanted cotton or white gold to become a major export. They were successful and today Uzbekistan is one of the world's largest exporters of cotton. Unfortunately this action essentially eliminated any river inflow to the Aral Sea and caused it to disappear almost completely.


FIGURE 13.24

Map of Aral Sea Area Map shows lake size in 1960 and political boundaries of 2011. Countries in yellow are at least partially in Aral Sea drainage basin. Source: Wikimedia Commons

In 1960 Aral Sea was the fourth largest inland water body; only the Caspian Sea, Lake Superior, and Lake Victoria were larger. Since then, it has progressively shrunk due to evaporation and lack of recharge by rivers. Before 1965 the Aral Sea received 2060 km3 of fresh water per year from rivers and by the early 1980s it received none. By 2007 the Aral Sea shrank to about 10% of its original size and its salinity increased from about 1% dissolved salt to about 10% dissolved salt, which is 3 times more saline than seawater. These changes caused an enormous environmental impact. A once thriving shipping industry is dead as are the 24 species of fish that used to live there; the fish could not adapt to the more saline waters. The current shoreline is tens of kilometers from former fishing towns and commercial ports. Large shipping boats lie in the dried up lakebed of dust and salt. A frustrating part of the river diversion project is that many of the irrigation canals were poorly built, allowing abundant water to leak or evaporate. An increasing number of dust storms blow salt, pesticides, and herbicides into nearby towns causing a variety of respiratory illnesses including tuberculosis.

FIGURE 13.25
An Abandoned Ship This abandoned ship lies in a dried up lake bed that was the Aral Sea near Aral, Kazakhstan
Source: Staecker at Wikimedia Commons

The wetlands of the two river deltas and their associated ecosystems have disappeared. The regional climate is drier and has greater temperature extremes due to the absence of moisture and moderating influence from the lake. In 2003 some lake restoration work began on the northern part of the Aral Sea and it provided some relief by raising water levels and reducing salinity somewhat. The southern part of the Aral Sea has seen no relief and remains nearly completely dry. The destruction of the Aral Sea is one of the planet's biggest environmental disasters and it is caused entirely by humans. Lake Chad in Africa is another example of a massive lake that has nearly disappeared for the same reasons as the Aral Sea. Aral Sea and Lake Chad are the most extreme examples of large lakes destroyed by unsustainable diversions of river water. Other lakes that have shrunk significantly due to human diversions of water include the Dead Sea in the Middle East, Lake Manchar in Pakistan, and Owens Lake and Mono Lake, both in California.

# 13.6 Resources

## Summary

Precipitation—a major control of fresh water availability—is unevenly distributed around the globe. More precipitation falls near the equator, and landmasses there are characterized by a tropical rainforest climate. Less precipitation tends to fall near 2030 north and south latitude, where the world's largest deserts are located. The water crisis refers to a global situation where people in many areas lack access to sufficient water or clean water or both. The current and future water crisis requires multiple approaches to extending our fresh water supply and moving towards sustainability. Some of the longstanding traditional approaches include dams and aqueducts. Water pollution is the contamination of water by an excess amount of a substance that can cause harm to human beings and the ecosystem. The level of water pollution depends on the abundance of the pollutant, the ecological impact of the pollutant, and the use of the water. The most deadly form of water pollution, pathogenic microorganisms that cause waterborne diseases, kills almost 2 million people in underdeveloped countries every year. Resolution of the global water pollution crisis requires multiple approaches to improve the quality of fresh water. The best strategy for addressing this problem is proper sewage treatment. Untreated sewage is not only a major cause of pathogenic diseases, but also a major source of other pollutants, including oxygen-demanding waste, plant nutrients, and toxic heavy metals.

## Review Questions

1. What is the water cycle and why is it important to fresh water resources?
2. What should society learn from the case history of the Aral Sea?
3. Why is society facing a crisis involving water supply and how can we solve it?
4. What are the major kinds of water pollutants and how do they degrade water quality?
5. How would you rank the water pollution problems described in this chapter? Why?
6. Why is untreated sewage such an important water pollutant to remediate?
7. Why are people facing a crisis involving water pollution and how can we solve it?

# 13.7 References

Theis, T. & Tomkin, J. (Eds.). (2015). *Sustainability: A comprehensive foundation*. Retrieved from http://cnx.org/contents/1741effd-9cda-4b2b-a91e-003e6f587263@43.5. Available under Creative Commons Attribution 4.0 International License. (CC BY 4.0). Modified from original.

## Supplementary Images

Leonard, G. (2006). ESQUEMPEQUE-EN. (JPG). Retrieved from https://en.wikipedia.org/wiki/File:ESQUEMPEQUE-EN.jpg.

# CHAPTER 14 Conventional and Sustainable Energy

## Chapter Outline



FIGURE 14.1

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

CGP Grey. (2009). Windmills. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Windmills_4890293313.jpg.

### Learning Outcomes

After studying this chapter, you should be able to:

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

## 14.1 Challenges and Impacts of Energy Use

### Introduction

Energy to illuminate, heat and cool our homes, businesses and institutions, manufacture products, and drive our transportation systems comes from a variety of sources that are originate from our planet and solar system (Theis & Tomkin, 2015). This provides a social and economic benefit to society. The earth's core provides geothermal energy. The gravitational pull of moon and sun create tides. The sun makes power in multiple ways. By itself, the sun generates direct solar power. The sun's radiation in combination with the hydrologic cycle can make wind power and hydroelectric power. Through **photosynthesis**, plants grow making wood and biomass that decay after they die into organic matter. Over the course of thousands of years, this decay results in fossil fuels that have concentrated or stored energy. Each of these types of energy can be defined as **renewable** or **non-renewable** fuels and they each have some environmental and health cost. Fossil fuel reserves are not distributed equally around the planet, nor are consumption and demand. We will see in this chapter that fuel distribution is critical to the sustainability of fossil fuel resources for a given geographic area. Making energy requires an input of energy so it is important to look at the net energy generated – the difference of the energy produced less the energy invested.

### Environmental and Health Challenges of Energy Use

The environmental impacts of energy use on humans and the planet can happen anywhere during the life cycle of the energy source. The impacts begin with the extraction of the resource. They continue with the processing, purification or manufacture of the source, its transportation to place of energy generation, effects from the generation of energy including use of water, air, and land, and end with the disposal of waste generated during the process. Extraction of fossil fuels, especially as the more conventional sources are depleted, takes a high toll on the natural environment. As we mine deeper into mountains, further out at sea, or further into pristine habitats, we risk damaging fragile environments, and the results of accidents or natural disasters during extraction processes can be devastating. Fossils fuels are often located far from where they are utilized so they need to be transported by pipeline, tankers, rail or trucks. These all present the potential for accidents, leakage and spills. When transported by rail or truck energy must be expended and pollutants are generated. Processing of petroleum, gas and coal generates various types of emissions and wastes, as well as utilizes water resources. Production of energy at power plants results in air, water, and, often, waste emissions. Power plants are highly regulated in the Unites States by federal and state law under the Clean Air and Clean Water Acts, while nuclear power plants are regulated by the Nuclear Regulatory Commission. As long as the facilities are complying, much of the environmental impact is mitigated by treating the emissions and using proper waste disposal methods. However, from a sustainability perspective these still present environmental threats over the long run and have a complex variety of issues around them. Figure 14.2 summarizes these challenges.

### Geopolitical Challenges of Fossil Fuels

The use of fossil fuels has allowed much of the global population to reach a higher standard of living. However, this dependence on fossil fuels results in many significant impacts on society. Our modern technologies and services, such as transportation, landscaping, and plastics production depend in many ways on fossil fuels. Meaning, if supplies become limited or extremely costly, our economies are vulnerable. If countries do not have fossil fuel reserves of their own, they incur even more risk. The United States has become more and more dependent on foreign oil since 1970 when our own oil production peaked. The United States imported over half of the crude

| | IMPACT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOURCE | Air Emissions lbs/MWh* | | | | Water Resources | | | Water Discharges | Solid Waste | Land Resources | | | |
| | $CO_2$ | NOx | $SO_2$ | Other | Qty | Use | Aquatic Life | | | Extraction | Plant building | Aesthetics | Other |
| Coal | 2,249 | 6 | 13 | Mercury | Large | Mining | Yes | Pollutants & heat | Ash from plant, mining & clean stack gas | Yes | Yes | Yes | |
| | | | | | | Cooling at plants | | Rain run-off from coal piles - lead & arsenic | | | | | |
| Oil | 1,672 | 4 | 12 | PM, lead, VOCs | Large | Steam & cooling | Yes | Treated wastewater from refineries | Sludge from refining & other solid waste with toxics & metals | Yes | Yes | | |
| | | | | | | Drilling water | | Drilling can contaminate underground water | | | | | |
| | | | | | | Refineries | | Spills during shipping | | | | | |
| Natural gas | 1,135 | 1.7 | 0.1 | Methane when not flared | Little | Combustion | Yes | Pollutants & heat | Not much | Yes | Yes | | |
| | | | | | Large | Hydraulic fracturing | | Haz chemicals from fracturing flow into surrounding area | | | | | |
| | | | | | | Remove impurities while mining | | | | | | | |
| Nuclear | 0 | 0 | 0 | 0 | Large | Plants, steam production, cooling | Yes | Heavy metals & salts in system<br>Waste from mining contaminates water | Radioactive waste is problematic2000 me-tons/yr in US | | Yes | | Waste storage |
| Hydroelectric | | | | Methane from vegetation build up | Large | Dam affects flow of rivers | Yes | None | None | | | Yes | Salmon in turbines |
| Municipal Solid waste | 3,685 (1/2 from fossil fuels) | 6.7 | 1.2 | | Large | Steam & cooling | Yes | Pollutants & heat | Reduces waste to landfills but makes possibly toxic ash | | Yes | Yes | |
| Biomass | Recycles carbon, less than fossil fuel | | | | Large | Steam & cooling | Yes | Pollutants & heat | Ash | | Yes | | Competes w/food crops |
| Solar | Negligible | | | | None unless making steam | | No | None | Minimal has waste from cell production | | | | Possibly wildlife |
| Geothermal | Negligible | | | | Small | | | Contamination from drilling & extraction | | | | | |

FIGURE 14.2

Environmental Impacts of Nonrenewable and Renewable Electricity Sources Source: C. Klein-Banai using data from U.S. Energy Information Administration and U.S. Environmental Protection Agency

oil and refined petroleum products that we consumed during 2009. Just over half of these imports came from the Western Hemisphere (see Figure 14.3).

The holder of oil reserves in the oil market is the **Organization of Petroleum Exporting Countries,** (OPEC) (see Figure 14.4). As of January 2009, there were 12 member countries in OPEC: Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. OPEC attempts to influence the amount of oil available to the world by assigning a production quota to each member except Iraq, for which no quota is presently set. Overall compliance with these quotas is mixed since the individual countries make the actual production decisions. All of these countries have a national oil company but also allow international oil companies to operate within their borders. They can restrict the amounts of production by those oil companies. Therefore, the OPEC countries have a large influence on how much of world demand is met by OPEC and non-OPEC supply. A recent example of this is the price increases that occurred during the year 2011 after multiple popular uprisings in Arab countries, including Libya.

This pressure has lead the United States to developing policies that would reduce reliance on foreign oil such as developing additional domestic sources and obtaining it from non-Middle Eastern countries such as Canada, Mexico,

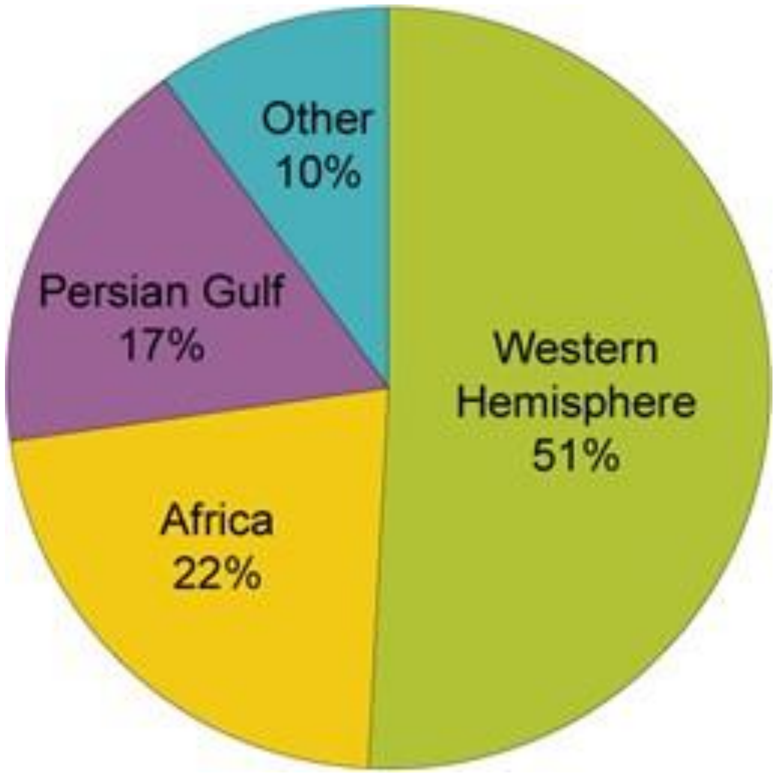


FIGURE 14.3

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

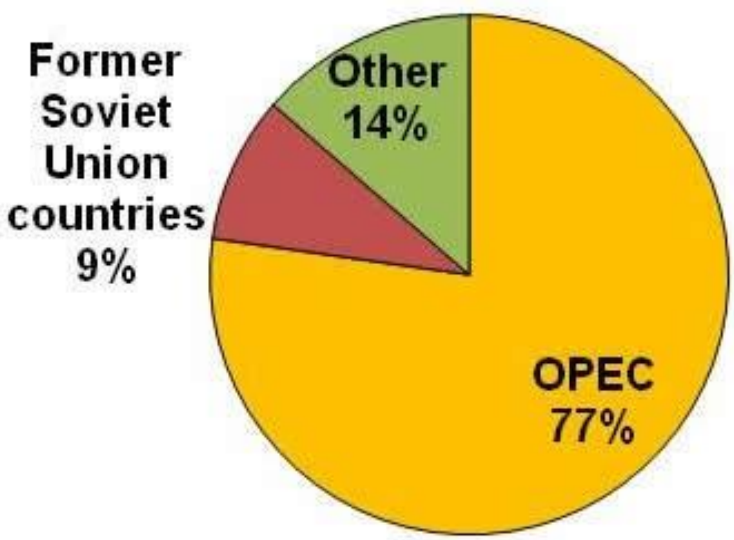


FIGURE 14.4

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

Venezuela, and Nigeria. However, since fossil fuel reserves create jobs and provide dividends to investors, a lot is at stake in a nation that has these reserves. Depending on whether that oil wealth is shared with the country's inhabitants or retained by the oil companies and dictatorships, as in Nigeria prior to the 1990s, a nation with fossil fuel reserves may benefit or come out even worse.

## Nonrenewable Energy and the Environment

Fossil fuels are also known as non-renewable energy because it takes thousands of years for the earth to regenerate them. The three main fuel sources come in all phases – solid, liquid, and gas. One overriding concern is the carbon dioxide emissions that contribute to climate change. Figure 14.5 displays the relationship between fuel type and carbon emissions.

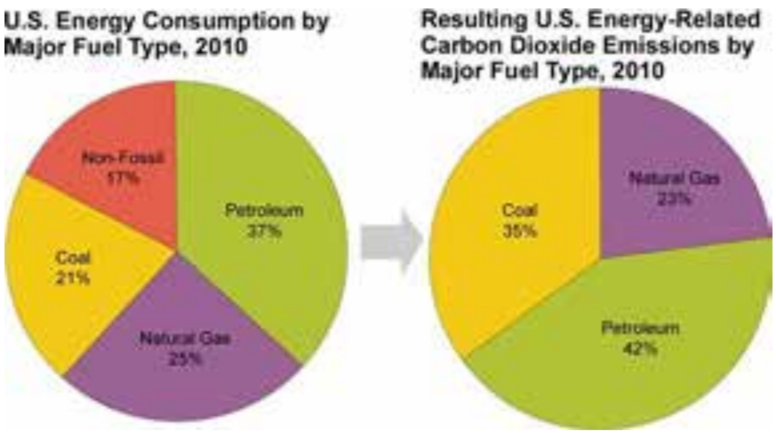


FIGURE 14.5

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

# 14.2 Non-Renewable Energy Sources

## Liquid Fossil Fuel: Petroleum

Thirty seven percent of the world's energy consumption and 43 percent of the United States energy consumption comes from oil (Theis & Tomkin, 2015). Most of the oil production is in the Gulf region. Scientists and policy-makers often discuss the question of when the world will reach peak oil production, and there are a lot of variables in that equation, but it is generally thought that peak oil will be reached by the middle of the 21st Century. Currently world reserves are 1.3 trillion barrels, or 45 years left at current level of production, but we may reduce production as supplies run low.

### Environmental Impacts of Oil Extraction and Refining

Oil is usually found one to two miles (1.6 – 3.2 km) below the surface. Oil refineries separate the mix of crude oil into the different types for gas, diesel fuel, tar, and asphalt. To find and extract oil workers must drill deep below ocean floor. As the United States tries to extract more oil from its own resources, we are drilling even deeper into the earth and increasing the environmental risks.

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

Once oil is found and extracted it must be refined. Oil refining is one of top sources of air pollution in the United States for volatile organic hydrocarbons and toxic emissions, and the single largest source of carcinogenic benzene. When petroleum is burned as gasoline or diesel, or to make electricity or to power boilers for heat, it produces a number of emissions that have a detrimental effect on the environment and human health:

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

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

## Solid Fossil Fuel: Coal

Coal comes from organic matter that was compressed under high pressure to become a dense, solid carbon structure over thousands to millions of years. Due to its relatively **low cost and abundance**, coal is used to generate about half of the electricity consumed in the United States. Coal is the largest domestically produced source of energy. Figure Historic U.S. Coal Production shows how coal production has doubled in the United States over the last sixty year. Current world reserves are estimated at **826,000 million tonnes**, with nearly 30 percent of that in the United States. It is a major fuel resource that the United States controls domestically.

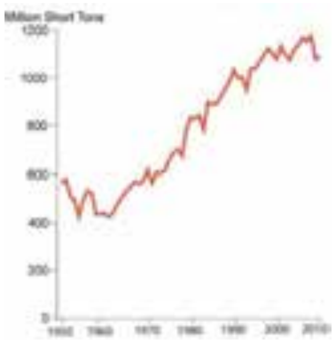


FIGURE 14.6

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

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

Traditional underground mining is risky to mine workers due to the risk of entrapment or death. Over the last 15 years, the U.S. Mine Safety and Health Administration has published the number of mine worker fatalities and it has varied from 18-48 per year.

Twenty-nine miners died on April 6, 2010 in an explosion at the Upper Big Branch coal mine in West Virginia, contributing to the uptick in deaths between 2009 and 2010. In other countries, with less safety regulations, accidents occur more frequently. In May 2011, for example, three people died and 11 were trapped in a coalmine in Mexico for several days. There is also risk of getting black lung disease (pneumoconiosis) **This is a disease of the lungs caused by the inhalation of coal dust over a long period of time.** It causes coughing and shortness of breath. If exposure is stopped the outcome is good. However, the complicated form may cause shortness of breath that gets increasingly worse.

**Mountain Top Mining** (MTM), while less hazardous to workers, has particularly detrimental effects on land resources. MTM is a surface mining practice involving the removal of mountaintops to expose coal seams, and disposing of the associated mining waste in adjacent valleys – "valley fills."

The following are some examples of the impact of MTM:

- an increase of minerals in the water that negatively impact fish and macroinvertebrates, leading to less diverse and more pollutant-tolerant species
- streams are sometimes covered up by silt from mining
- the re-growth of trees and woody plants on regraded land may be slowed due to compacted soils
- affects the diversity of bird and amphibian species in the area since the ecosystem changes from wooded areas

FIGURE 14.7

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

to other

- there may be social, economic and heritage issues created by the loss of wooded land that may have been important to traditions and economies of the area

## Gaseous Fossil Fuel: Natural Gas

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

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

In the last few years a new reserve of natural gas has been identified **- shale resources.** The United States possesses 2,552 trillion cubic feet (Tcf) (72.27 trillion cubic meters) of potential natural gas resources, with shale resources accounting for 827 Tcf (23.42 tcm). As gas prices increased it has become more economical to extract the gas from shale. Figure **U.S. Natural Gas Supply**, 1990-2035 shows the past and forecasted U.S. natural gas production and the various sources. The current reserves are enough to last about 110 years at the 2009 rate of U.S. consumption (about 22.8 Tcf per year -645.7 bcm per year).

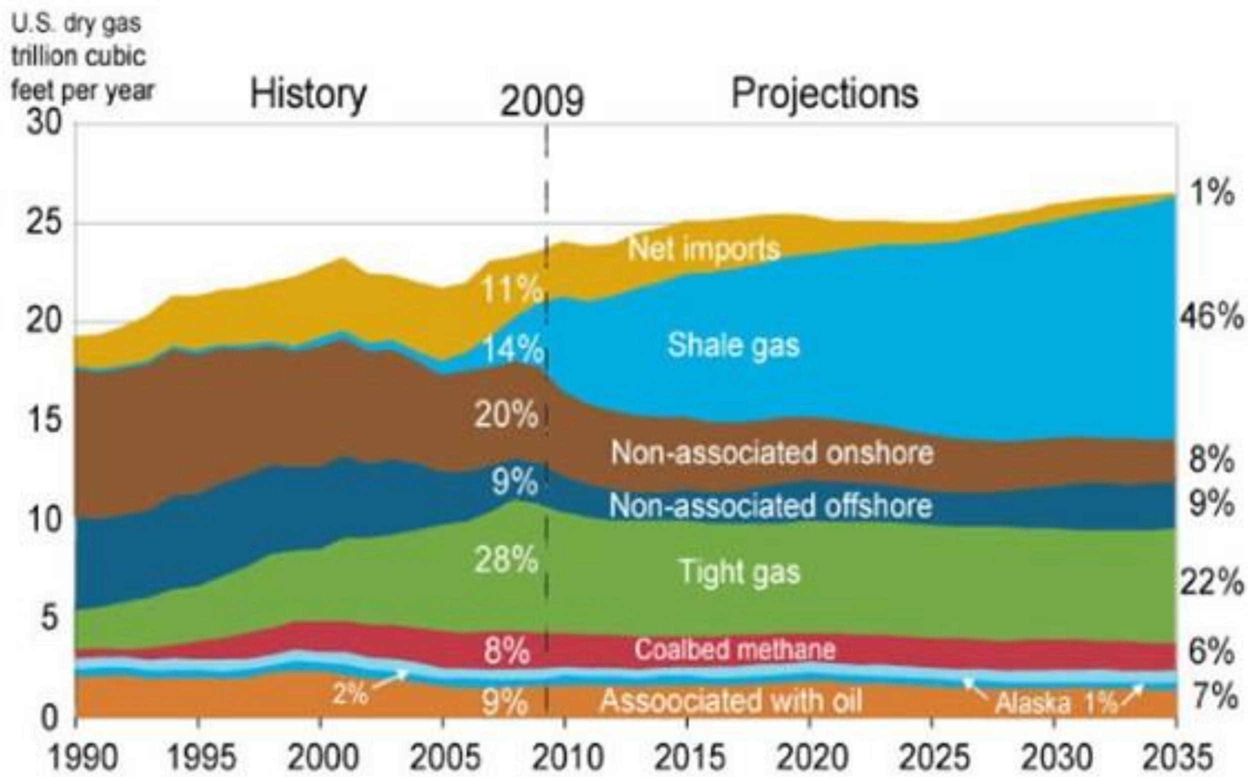


FIGURE 14.8

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

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

## Environmental Impacts of Exploration, Drilling, and Production

Land resources are affected when geologists explore for natural gas deposits on land, as vehicles disturb vegetation and soils. Road clearing, pipeline and drill pad construction also affect natural habitats by clearing and digging. Natural gas production can also result in the production of large volumes of contaminated water. This water has to be properly handled, stored, and treated so that it does not pollute land and water supplies. Extraction of shale gas is more problematic than traditional sources due to a process nicknamed **fracking** or **fracturing of wells**, since it requires large amounts of water (see Figure 14.9). The technique uses high-pressure fluids to fracture the normally hard shale deposits and release gas and oil trapped inside the rock. To promote the flow of gas out of the rock, small particles of solids are included in the fracturing liquids to lodge in the shale cracks and keep them open after the liquids are depressurized. The considerable use of water may affect the availability of water for other uses in some regions and this can affect aquatic habitats. If mismanaged, hydraulic fracturing fluid can be released by spills, leaks, or various other exposure pathways. The fluid contains potentially hazardous chemicals such as hydrochloric acid, glutaraldehyde, petroleum distillate, and ethylene glycol. The risks of fracking have been highlighted in popular culture in the documentary, Gasland (2010).

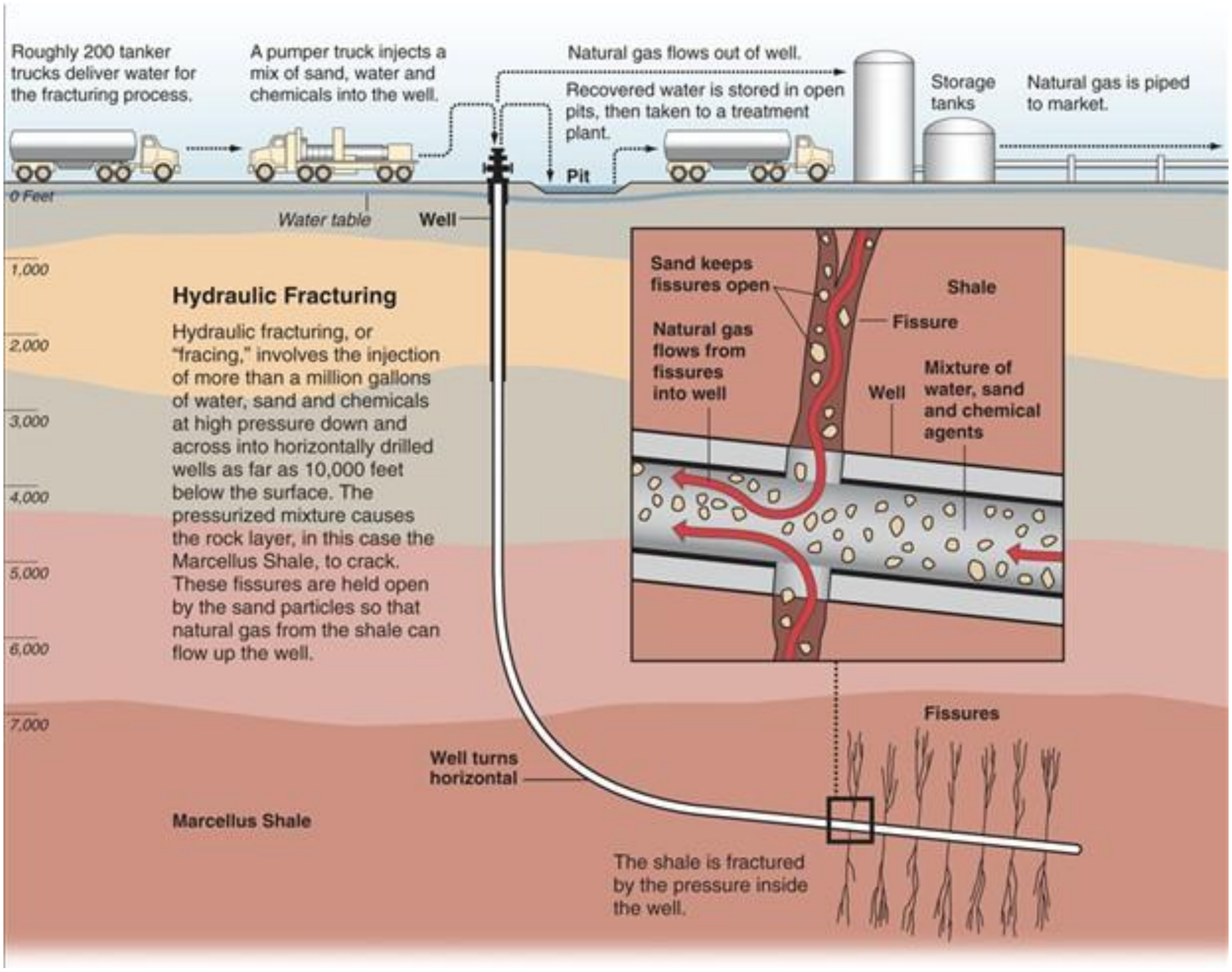


FIGURE 14.9

Graphic illustrates the process of hydraulic fracturing.

ProPublica. (2017). Fracking. (JPG). Retrieved from http://www.propublica.org/special/hydraulic-fracturing-national.

**Fracking** also produces large amounts of wastewater, which may contain dissolved chemicals from the hydraulic fluid and other contaminants that require treatment before disposal or reuse. Because of the quantities of water used and the complexities inherent in treating some of the wastewater components, treatment and disposal is an important and challenging issue.

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

## Contributions of Coal and Gas to Electricity Generation

At present the fossil fuels used for electricity generation are predominantly coal (45 percent) and gas (23 percent); petroleum accounts for approximately 1 percent. Coal electricity traces its origins to the early 20th Century, when it was the natural fuel for steam engines given its abundance, high energy density and low cost. Gas is a later addition to the fossil electricity mix, arriving in significant quantities after World War II and with its greatest growth since 1990. Of the two fuels, coal emits almost twice the carbon dioxide as gas for the same heat output, making it significantly greater contributor to global warming and climate change.

### The Future of Gas and Coal

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

Beyond a trend from coal to gas for electricity generation, there is a need to deal with the carbon emissions from the fossil production of electricity. Figure 14.12 shows the size of these emissions compared to natural fluxes between ocean and atmosphere and from vegetation and land use. The anthropogenic fluxes are small by comparison, yet have a large effect on the concentration of carbon dioxide in the atmosphere. The reason is the step-wise dynamics of the carbon cycle. The ultimate storage repository for carbon emissions is the deep ocean, with abundant capacity to absorb the relatively small flux from fossil fuel combustion. Transfer to the deep ocean, however, occurs in three steps: first to the atmosphere, then to the shallow ocean, and finally to the deep ocean. The **bottleneck** is the slow transfer of carbon dioxide from the shallow ocean to the deep ocean, governed by the great ocean conveyor belt or thermohaline circulation illustrated in Figure 14.12. The great ocean conveyor belt takes 400 – 1000 years to complete one cycle. While carbon dioxide waits to be transported to the deep ocean, it saturates the shallow ocean and "backs up" in the atmosphere causing global warming and threatening climate change. If carbon emissions are to be captured and stored (or "sequestered") they must be trapped for thousands of years while the atmosphere adjusts to past and future carbon emissions.

**Sequestration** of carbon dioxide in underground geologic formations is one process that, in principle, has the capacity to handle fossil fuel carbon emissions, chemical reaction of carbon dioxide to a stable solid form is another. For sequestration, there are fundamental challenges that must be understood and resolved before the process can be implemented on a wide scale.

The chemical reactions and migration routes through the porous rocks in which carbon dioxide is stored underground are largely unknown. Depending on the rock environment, stable solid compounds could form that would effectively remove the sequestered carbon dioxide from the environment. Alternatively, it could remain as carbon dioxide or transform to a mobile species and migrate long distances, finally finding an escape route to the atmosphere where it could resume its contribution to greenhouse warming or cause new environmental damage. The requirement on long term sequestration is severe: a leak rate of 1 percent means that all the carbon dioxide sequestered in the first year escapes in a century, a blink of the eye on the timescale of climate change.

## Nuclear Power

Nuclear power plants produce **no carbon dioxide** and, therefore, are often considered an alternative fuel, when the main concern is climate change. Currently, world production is about 19.1 trillion KWh, with the United

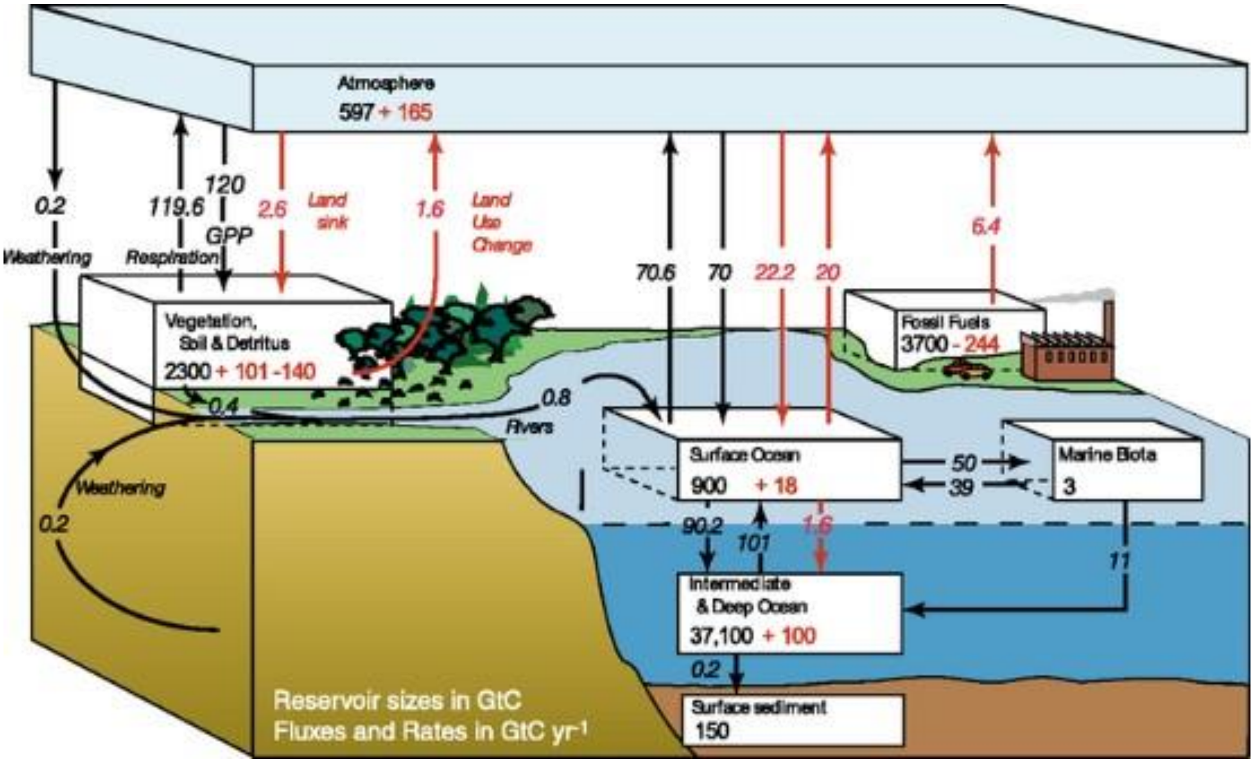


FIGURE 14.10

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

States producing and consuming about 22 percent of that. Nuclear power provides about nine percent of our total consumption for electricity (see Figure 14.12).

However, there are environmental challenges with nuclear power. Mining and refining uranium ore and making reactor fuel demands a lot of energy. The plants themselves are made of metal and concrete which also requires energy to make. The main environmental challenge for nuclear power is the wastes including uranium mill tailings, spent (used) reactor fuel, and other radioactive wastes. These materials have **long radioactive half-lives** and thus remain a threat to human health for thousands of years. The U.S. Nuclear Regulatory Commission regulates the operation of nuclear power plants and the handling, transportation, storage, and disposal of radioactive materials to protect human health and the environment.

By volume **, uranium mill tailings** are the largest waste and they contain the radioactive element radium, which decays to produce **radon**, a radioactive gas. This waste is placed near the processing facility or mill where they come from, and are covered with a barrier of a material such as clay to prevent radon from escaping into the atmosphere and then a layer of soil, rocks, or other materials to prevent erosion of the sealing barrier.

**High-level radioactive waste** consists of used nuclear reactor fuel. This fuel is in a solid form consisting of small fuel pellets in long metal tubes and must be stored and handled with multiple containment, first cooled by water and later in special outdoor concrete or steel containers that are cooled by air. *There is no long-term storage facility for this fuel in the United States*.

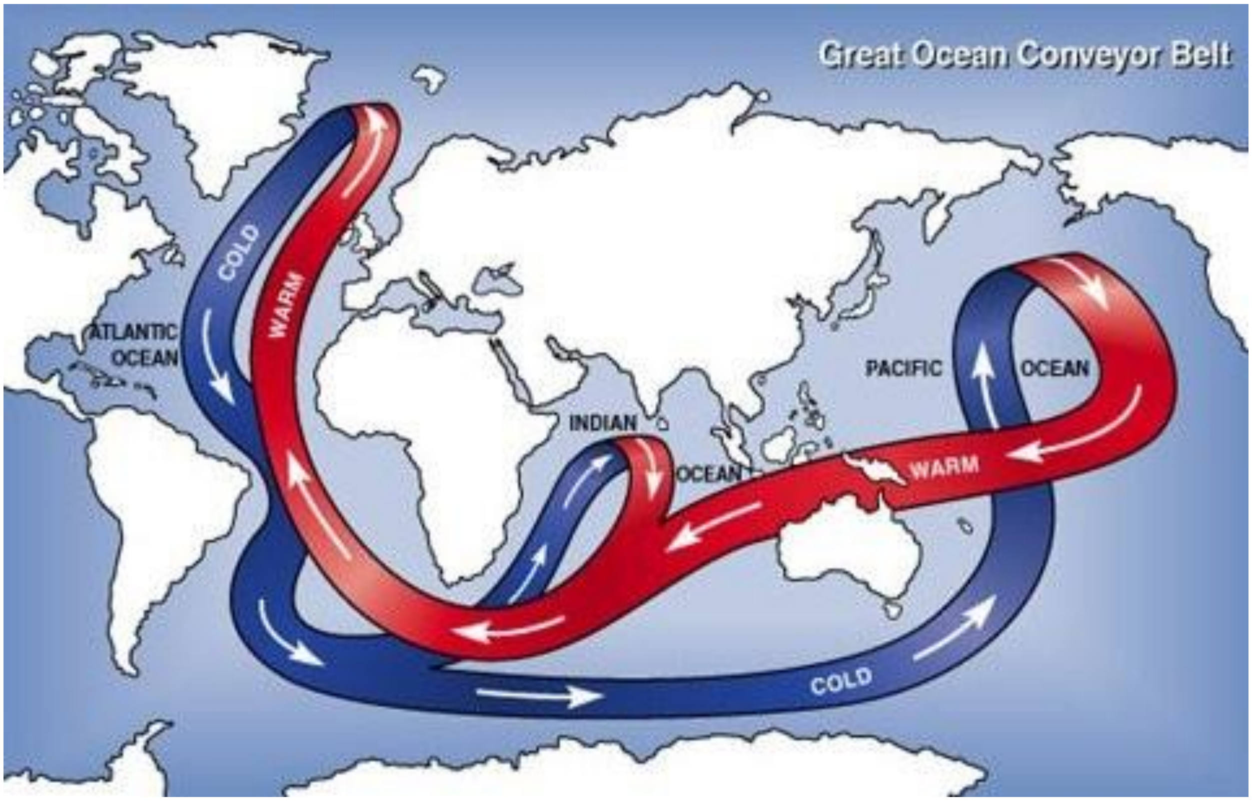


FIGURE 14.11

Great Ocean Conveyor Belt The great ocean conveyor belt (or thermohaline current) sends warm surface currents from the Pacific to Atlantic oceans and cold deep currents in the opposite direction. The conveyor belt is responsible for transporting dissolved carbon dioxide from the relatively small reservoir of the shallow ocean to much larger reservoir of the deep ocean. It takes 400 - 1000 years to complete one cycle. Source: Argonne National Laboratory

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

**NOTE**

**Fukushima Daiichi Nuclear PowerStation**

- March 11, 2011: Magnitude 9.0 earthquake 231 miles northeast of Tokyo. Less than 1 hour later a 14m tsunami hit
- 50 power station employees worked around the clock to try to stabilize the situation

United States' nuclear reactors have containment vessels that are designed to withstand extreme weather events and earthquakes. However, in the aftermath of the Japan incident, they are reviewing their facilities, policies, and procedures.

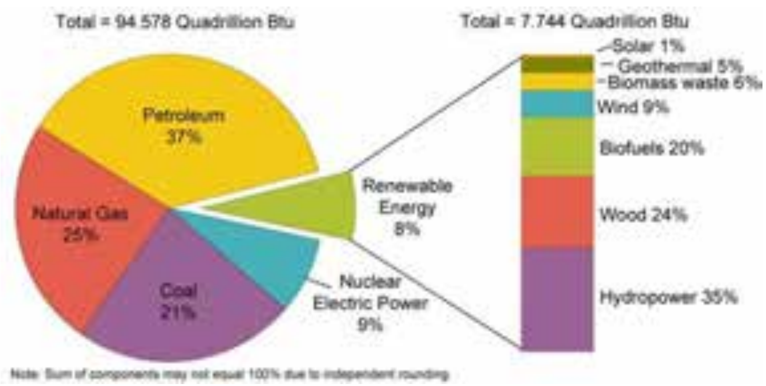


FIGURE 14.12

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

## Debating Nuclear Energy

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

Nuclear electricity came on the energy scene remarkably quickly. Following the development of nuclear technology at the end of World War II for military ends, nuclear energy quickly acquired a new peacetime path for inexpensive production of electricity. Eleven years after the end of World War II, in 1956, a very short time in energy terms, the first commercial nuclear reactor produced electricity at Calder Hall in Sellafield, England. The number of nuclear reactors grew steadily to more than 400 by 1990, four years after the Chernobyl disaster in 1986 and eleven years following Three Mile Island in 1979. Since 1990, the number of operating reactors has remained approximately flat, with new construction balancing decommissioning, due to public and government reluctance to proceed with nuclear electricity expansion plans. Figure Growth of Fuels Used to Produce Electricity in the United States and Figure Nuclear Share of United States Electricity Generation show the development and status of nuclear power in the United States, a reflection of its worldwide growth.

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

There are two basic routes for handling the spent fuel of nuclear reactors: once through and reprocessing. Once through stores spent fuel following a single pass through the reactor, first in pools at the reactor site while it cools radioactively and thermally, then in a long-term geologic storage site, where it must remain for hundreds of thousands of years. Reprocessing separates the useable fraction of spent fuel and recycles it through the reactor, using a greater fraction of its energy content for electricity production, and sends the remaining high-level waste to permanent geologic storage. The primary motivation for recycling is greater use of fuel resources, extracting ~ 25 percent more energy than the once through cycle. A secondary motivation for recycling is a significant reduction of the permanent geologic storage space (by a factor of ~ 5 or more) and time (from hundreds of thousands of years to thousands of years). While these advantages seem natural and appealing from a sustainability perspective, they are complicated by the risk of theft of nuclear material from the reprocessing cycle for use in illicit weapons production or other non-sustainable ends. At present, France, the United Kingdom, Russia, Japan and China engage in some form of reprocessing; the United States, Sweden and Finland do not reprocess.

## The Global Dependence of Transportation on Oil

**Liquid petroleum fuels** and **electricity** are the two dominant **energy carriers** in the United States, oil accounting for 37 percent of primary energy and electricity for 38 percent. These two energy carriers account for a similar fraction of carbon emissions, 36 percent and 38 percent, respectively. Two thirds of oil consumption is devoted to transportation, providing fuel for cars, trucks, trains and airplanes. For the United States and most developed societies, transportation is woven into the fabric of our lives, a necessity as central to daily operations as food or shelter. The concentration of oil reserves in a few regions or the world (Figure Crude Oil Reserves) makes much of the world dependent on imported energy for transportation.

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

From a sustainability perspective, oil presents several challenges. First is the length of time over which the world's finite oil reserves can continue to supply rising demand. Second is the impact on global warming and climate change that carbon emissions from oil combustion will have, and third is the challenge of finding a sustainable replacement for oil for transportation. Although we know the general course of initial rise and ultimate fall that global oil production must take, we do not know with confidence the time scale over which it will play out.

The uncertainty of the timing of the peak in global oil production encourages us to find other issues and motivations for dealing with an inevitably unsustainable supply. A prime motivation is energy security, the threat that oil supplies could be interrupted by any of several events including weather, natural disaster, terrorism and geopolitics. Much of the world feels these threats are good reasons for concerted effort to find replacements for oil as our primary transportation fuel. A second motivation is the environmental damage and accumulation of greenhouse gases in the atmosphere due to transportation emissions. Unlike electricity generation, transportation emissions arise from millions of tiny sources, e.g. the tailpipes of cars and trucks and the exhaust of trains and airplanes.

The challenge of capturing and sequestering carbon dioxide from these distributed and moving sources is dramatically greater than from the large fixed sources of power plants. A more achievable objective may be replacing oil as a transportation fuel with biofuel that recycles naturally each year from tailpipes of cars to biofuel crops that do not compete with food crops. Other options include replacing liquid fuels with electricity produced domestically, or increasing the efficiency of vehicles by reducing their weight, regeneratively capturing braking energy, and improving engine efficiency. Each of these options has promise and each must overcome challenges.

Changes in the energy system are inevitably slow, because of the time needed to develop new technologies and the operational inertia of phasing out the infrastructure of an existing technology to make room for a successor. The transportation system exhibits this operational inertia, governed by the turnover time for the fleet of vehicles, about 15 years. Although that time scale is long compared to economic cycles, the profit horizon of corporations and the political horizon of elected officials, it is important to begin now to identify and develop sustainable alternatives to oil as a transportation fuel. The timescale from innovation of new approaches and materials to market deployment is typically 20 years or more, well matched to the operational inertia of the transportation system. The challenge is to initiate innovative research and development for alternative transportation systems and sustain it continuously until the alternatives are established.

# 14.3 Renewable Energy Sources

## Hydropower

Hydropower (hydro-electric) is considered a clean and renewable source of energy since it does not directly produce emissions of air pollutants and the source of power is regenerated (Theis & Tomkin, 2015). However, hydropower dams, reservoirs, and the operation of generators can have environmental impacts. Figure 14.13 shows the Hoover Power Plant located on the Colorado River. Hydropower provides 35 percent of the United States' renewable energy consumption. In 2003 capacity was at 96,000 MW and it was estimated that 30,000 MW capacity is undeveloped.

FIGURE 14.13 Hoover Power Plant View of Hoover Power Plant on the Colorado River as seen from above. Source: U.S. Department of the Interior

Migration of fish to their upstream spawning areas can be obstructed by a dam that is used to create a reservoir or to divert water to a run-of-river hydropower plant. A reservoir and operation of the dam can affect the natural water habitat due to changes in water temperatures, chemistry, flow characteristics, and silt loads, all of which can lead to significant changes in the ecology and physical characteristics of the river upstream and downstream. Construction of reservoirs may cause natural areas, farms, and archeological sites to be covered and force populations to relocate. Hydro turbines kill and injure some of the fish that pass through the turbine although there are ways to reduce that effect. In areas where salmon must travel upstream to spawn, such as along the Columbia River in Washington and Oregon, the dams get in the way. This problem can be partially alleviated by using "fish ladders" that help the salmon get up the dams.

Carbon dioxide and methane may also form in reservoirs where water is more stagnant and be emitted to the atmosphere. The exact amount of greenhouse gases produced from hydropower plant reservoirs is uncertain. If the reservoirs are located in tropical and temperate regions, including the United States, those emissions may be equal to or greater than the greenhouse effect of the carbon dioxide emissions from an equivalent amount of electricity generated with fossil fuels (EIA, 2011).

**Small hydropower systems**

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

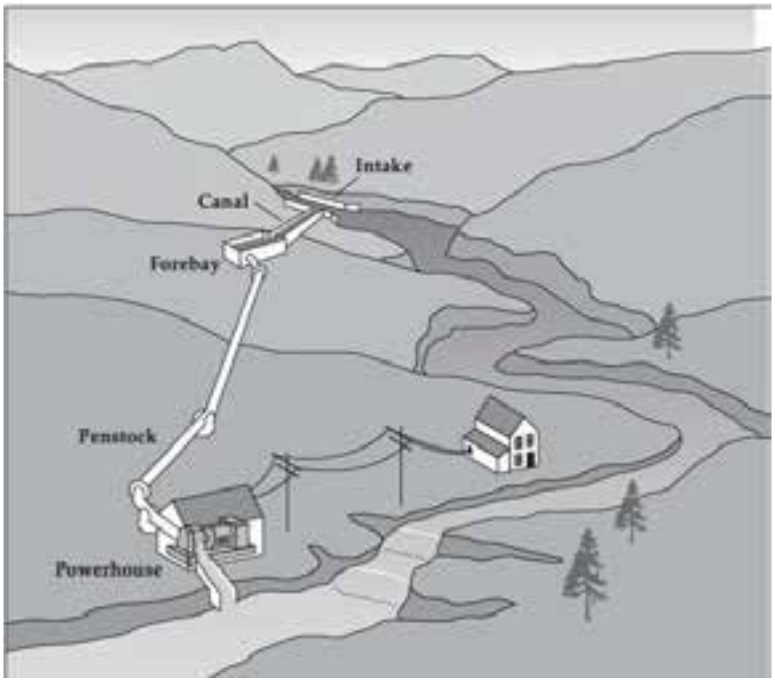


FIGURE 14.14

Microhydropower system. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity.

Small hydropower projects offer emissions-free power solutions for many remote communities throughout the world—such as those in Nepal, India, China, and Peru—as well as for highly industrialized countries, like the United States. *Small-hydro* systems are those that generate between .01 to 30 MW of electricity. Hydropower systems that generate up to 100 kilowatts (kW) of electricity are often called *micro-hydro* systems (Figure14.14). Most of the systems used by home and small business owners would qualify as microhydro systems. In fact, a 10 kW system generally can provide enough power for a large home, a small resort, or a hobby farm.

## Municipal Solid Waste

Waste to energy processes are gaining renewed interest as they can solve two problems at once – disposal of waste as landfill capacity decreases and production of energy from a renewable resource. Many of the environmental impacts are similar to those of a coal plant – air pollution, ash generation, etc. Since the fuel source is less standardized than coal and hazardous materials may be present in municipal solid waste (MSW), or garbage, incinerators and waste-to-energy power plants need to clean the stack gases of harmful materials. The U.S. EPA regulates these plants very strictly and requires anti-pollution devices to be installed. Also, while incinerating at high temperature many of the toxic chemicals may break down into less harmful compounds.

The ash from these plants may contain high concentrations of various metals that were present in the original waste. If ash is clean enough it can be "recycled" as an MSW landfill cover or to build roads, cement block and artificial reefs

## Biomass

Biomass is derived from plants. Examples include lumber mill sawdust, paper mill sludge, yard waste, or oat hulls from an oatmeal processing plant. A major challenge of biomass is determining if it is really a more sustainable option. It often takes energy to make energy and biomass is one example where the processing to make it may not be offset by the energy it produces. For example, biomass combustion may increase or decrease emission of air pollutants depending on the type of biomass and the types of fuels or energy sources that it replaces. Biomass reduces the demand for fossil fuels, but when the plants that are the sources of biomass are grown, a nearly equivalent amount of $CO_2$ is captured through photosynthesis, thus it recycles the carbon. If these materials are grown and harvested in a sustainable way there can be no net increase in $CO_2$emissions. Each type of biomass must be evaluated for its environmental and social impact in order to determine if it is really advancing sustainability and reducing environmental impacts.

FIGURE 14.15

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

## Solid Biomass: Burning Wood

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

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

### Gaseous Biomass: Landfill Gas or Biogas

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

### Liquid Biofuels: Ethanol and Biodiesel

Biofuels may be considered to be carbon-neutral because the plants that are used to make them (such as corn and sugarcane for ethanol, and soy beans and palm oil trees for biodiesel) absorb $CO_2$ as they grow and may offset the $CO_2$ produced when biofuels are made and burned. Calculating the net energy or $CO_2$ generated or reduced in the process of producing the biofuel is crucial to determining its environmental impact. Even if the environmental impact is net positive, the economic and social effects of growing plants for fuels need to be considered, since the land, fertilizers, and energy used to grow biofuel crops could be used to grow food crops instead. The competition of land for fuel vs. food can increase the price of food, which has a negative effect on society. It could also decrease the food supply increasing malnutrition and starvation globally. Biofuels may be derived from parts of plants not used for food (cellulosic biomass) thus reducing that impact. Cellulosic ethanol feedstock includes native prairie grasses, fast growing trees, sawdust, and even waste paper. Also, in some parts of the world, large areas of natural vegetation and forests have been cut down to grow sugar cane for ethanol and soybeans and palm-oil trees to make biodiesel. This is not sustainable land use.

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

Biodiesel can be made from used vegetable oil and has been produced on a very local basis. Compared to petroleum diesel, biodiesel combustion produces less sulfur oxides, particulate matter, carbon monoxide, and unburned and other hydrocarbons, but more nitrogen oxide.

### Social and Environmental Motivations for Biofuels Production

Biofuels are fuels made from biomass. The best known example is ethanol, which can be easily fermented from sugar cane juice, as is done in Brazil. Ethanol can also be fermented from broken down (saccarified) corn starch, as is mainly done in the United States. Most recently, efforts have been devoted to making drop-in replacement hydrocarbon biofuels called green gasoline, green diesel, or green jet fuel. This chapter discusses the need for biofuels, the types of biofuels that can be produced from the various available biomass feedstocks, and the advantages and disadvantages of each fuel and feedstock. The various ways of producing biofuels are also reviewed.

### The Need for Renewable Transportation Fuels

In crude oil, coal, and natural gas, (collectively called fossil fuels) our planet has provided us with sources of energy that have been easy to obtain and convert into useful fuels and chemicals. That situation will soon change, however, in a few decades for petroleum crude and in a few centuries for coal and natural gas. Peak oil refers to the peak in oil production that must occur as petroleum crude runs out.

Since oil is getting harder and harder to find, we now have to obtain it from less accessible places such as far under the ocean, which has led to hard-to-repair accidents such as the Deepwater Horizon oil spill in May, 2010. An additional effect is the higher cost of refining the petroleum since it comes from more remote locations or in less desirable forms such as thick, rocky "tar sand" or "oil sand" found in Canada or Venezuela. Overall, the use of petroleum crude cannot exceed the amount of petroleum that has been discovered, and assuming that no major oil discoveries lie ahead, the production of oil from crude must start to decrease. Some analysts think that this peak has already happened.

An additional aspect of oil scarcity is energy independence. The United States currently imports about two thirds of its petroleum, making it dependent on the beneficence of countries that possess large amounts of oil. Middle Eastern countries are among those with the highest oil reserves. With its economy and standard of living so based on imported petroleum crude it is easy to see why the United States is deeply involved in Middle East politics.

A second major motivation to move away from petroleum crude is global climate change. While the correlation of carbon dioxide ($CO_2$) concentration in the atmosphere to average global temperature is presently being debated, the rise of $CO_2$ in our atmosphere that has come from burning fossil fuel since the industrial revolution is from about 280 ppm to about 390 ppm at present, and cannot be denied. Energy sources such as wind, solar, nuclear, and biomass are needed that minimize or eliminate the release of atmospheric $CO_2$. Biomass is included in this list since the carbon that makes up plant fiber is taken from the atmosphere in the process of photosynthesis. Burning fuel derived from biomass releases the $CO_2$ back into the atmosphere, where it can again be incorporated into plant mass. The Energy Independence and Security Act (EISA) of 2007 defines an advanced biofuel as one that lowers lifecycle greenhouse gas emissions (emissions from all processes involved in obtaining, refining, and finally burning the fuel) by 60% relative to the baseline of 2005 petroleum crude.

## Geothermal Energy

Five percent of the United States' renewable energy portfolio is from geothermal energy. The subsurface temperature of the earth provides an endless energy resource. The environmental impact of geothermal energy depends on how it is being used. Direct use and heating applications have almost no negative impact on the environment.

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

Geothermal ground source systems utilize a heat-exchange system that runs in the subsurface about 20 feet (5 meters) below the surface where the ground is at a constant temperature. The system uses the earth as a heat source (in the winter) or a heat sink (in the summer). This reduces the energy consumption requires to generate heat from gas, steam, hot water, and chiller and conventional electric air-conditioning systems.

## Solar Energy

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

FIGURE 14.16

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

## Wind

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

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

Wind turbines do have a few environmental challenges. There are aesthetic concerns to some people when they see them on the landscape. A few wind turbines have caught on fire, and some have leaked lubricating fluids, though this is relatively rare. Some people do not like the sound that wind turbine blades make.

FIGURE 14.17

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

Turbines have been found to cause bird and bat deaths particularly if they are located along their migratory path. This is of particular concern if these are threatened or endangered species. There are ways to mitigate that impact and it is currently being researched.

There are some small impacts from the construction of wind projects or farms, such as the construction of service roads, the production of the turbines themselves, and the concrete for the foundations. However, overall analysis has found that turbines make much more energy than the amount used to make and install them.

## Interest in Renewable Energy

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

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

## Physical Origin of Renewable Energy

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

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

As relative newcomers to energy production, renewable energy typically operates at lower efficiency than its conventional counterparts. For example, the best commercial solar photovoltaic modules operate at about 20 percent efficiency, compared to nearly 60 percent efficiency for the best combined cycle natural gas turbines. Photovoltaic modules in the laboratory operate above 40 percent efficiency but are too expensive for general use, showing that there is ample headroom for performance improvements and cost reductions. Wind turbines are closer to their theoretical limit of 59 percent (known as Betz's law) often achieving 35 – 40 percent efficiency. Biomass is notoriously inefficient, typically converting less than one percent of incident sunlight to energy stored in the chemical bonds of its roots, stalks and leaves. Breeding and genetic modification may improve this poor energy efficiency, though hundreds of millions of years of evolution since the appearance of multicelled organisms have not produced a significant advance. Geothermal energy is already in the form of heat and temperature gradients, so that standard techniques of thermal engineering can be applied to improve efficiency. Wave and tidal energy, though demonstrated in several working plants, are at early stages of development and their technological development remains largely unexplored.

## Capacity and Geographical Distribution

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

The potential of renewable energy resources varies dramatically. Solar energy is by far the most plentiful, delivered to the surface of the earth at a rate of 120,000 Terawatts (TW), compared to the global human use of 15 TW. To put this in perspective, covering 100x100 km2 of desert with 10 percent efficient solar cells would produce 0.29 TW of power, about 12 percent of the global human demand for electricity. To supply all of the earth's electricity needs (2.4 TW in 2007) would require 7.5 such squares, an area about the size of Panama (0.05 percent of the earth's total land area). The world's conventional oil reserves are estimated at three trillion barrels, including all the oil that has already been recovered and that remain for future recovery. The solar energy equivalent of these oil reserves is delivered to the earth by the sun in 1.5 days.

The global potential for producing electricity and transportation fuels from solar, wind and biomass is limited by geographical availability of land suitable for generating each kind of energy (described as the geographical potential), the technical efficiency of the conversion process (reducing the geographical potential to the technical potential), and the economic cost of construction and operation of the conversion technology (reducing the technical potential to the economic potential). The degree to which the global potential of renewable resources is actually developed depends on many unknown factors such as the future extent of economic and technological advancement in the developing and developed worlds, the degree of globalization through business, intellectual and social links among countries and regions, and the relative importance of environmental and social agendas compared to economic and material objectives. Scenarios evaluating the development of renewable energy resources under various assumptions about the world's economic, technological and social trajectories show that solar energy has 20-50 times the potential of wind or biomass for producing electricity, and that each separately has sufficient potential to provide the world's electricity needs in 2050 (de Vries, 2007).

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

## Wind and Solar Resources in the United States

The United States has abundant renewable resources. The solar irradiation in the southwestern United States is exceptional, equivalent to that of Africa and Australia, which contain the best solar resources in the world. Much of the United States has solar irradiation as good or better than Spain, considered the best in Europe, and much higher than Germany. The variation in irradiation over the United States is about a factor two, quite homogeneous compared to other renewable resources. The size of the United States adds to its resource, making it a prime opportunity for solar development.

The wind resource of the United States, while abundant, is less homogeneous. Strong winds require steady gradients of temperature and pressure to drive and sustain them, and these are frequently associated with topological features such as mountain ranges or coastlines. The onshore wind map of the United States shows this pattern, with the best wind along a north-south corridor roughly at mid-continent. Offshore winds over the Great Lakes and the east and west coasts are stronger and steadier though they cover smaller areas. The technical potential for onshore wind is over 8000 GW of capacity (Lu, 2009; Black & Veatch, 2007) and offshore is 800 – 3000 GW (Lu, 2009; Schwartz, Heimiller, Haymes, & Musial, 2010). For comparison, the United States used electricity in 2009 at the rate of 450 GW averaged over the day-night and summer-winter peaks and valleys.

## Barriers to Deployment

Renewable energy faces several barriers to its widespread deployment. Cost is one of the most serious. Although the cost of renewables has declined significantly in recent years, most are still higher in cost than traditional fossil alternatives. Fossil energy technologies have a longer experience in streamlining manufacturing, incorporating new materials, taking advantage of economies of scale and understanding the underlying physical and chemical phenomena of the energy conversion process. The lowest cost electricity is generated by natural gas and coal, with hydro and wind among the renewable challengers. Cost, however, is not an isolated metric; it must be compared with the alternatives. One of the uncertainties of the present business environment is the ultimate cost of carbon emissions. If governments put a price on carbon emission to compensate the social cost of global warming and the threat of climate change, the relative cost of renewables will become more appealing even if their absolute cost does not change. This policy uncertainty in the eventual cost of carbon-based power generation is a major factor in the future economic appeal of renewable energy.

A second barrier to widespread deployment of renewable energy is public opinion. In the consumer market, sales directly sample public opinion and the connection between deployment and public acceptance is immediate. Renewable energy is not a choice that individual consumers make. Instead, energy choices are made by government policy makers at city, state and federal levels, who balance concerns for the common good, for “fairness” to stakeholders, and for economic cost. Nevertheless, public acceptance is a major factor in balancing these concerns: a strongly favored or disfavored energy option will be reflected in government decisions through representatives elected by or responding to the public. The range of acceptance goes from strongly positive for solar to strongly negative for nuclear. The disparity in the public acceptance and economic cost of these two energy alternatives is striking: solar is at once the most expensive alternative and the most acceptable to the public.

The importance of public opinion is illustrated by the Fukushima nuclear disaster of 2011. The earthquake and tsunami that ultimately caused meltdown of fuel in several reactors of the Fukushima complex and release of radiation in a populated area caused many of the public in many countries to question the safety of reactors and of the nuclear electricity enterprise generally. The response was rapid, with some countries registering public consensus for drastic action such as shutting down nuclear electricity when the licenses for the presently operating reactors expire. Although its ultimate resolution is uncertain, the sudden and serious impact of the Fukushima event on public opinion shows the key role that social acceptance plays in determining our energy trajectory.

# 14.4 Combined Heat and Power as an Alternative Energy Source

Electricity in the United States is generated, for the most part, from central station power plants at a conversion efficiency of roughly 30 to 35 percent (EEA, 2013). Meaning, for every 100 units of fuel energy into a simple cycle central station electric power plant, we get only 30 to 35 units of electricity. The remainder of the energy in the fuel is lost to the atmosphere in the form of heat.

The thermal requirements of our buildings and facilities are generally provided **on-site** through the use of a boiler or furnace. The efficiencies of this equipment have improved over the years and now it is common to have boilers and furnaces in commercial and industrial facilities with efficiencies of 80 percent and higher. Meaning, for every 100 units of fuel energy into the boiler/furnace, we get about 80 units of useful thermal energy.

Commercial and industrial facilities that utilize the conventional energy system found in the United States (electricity supplied from the electric grid and thermal energy produced on-site through the use of a boiler/furnace) will often times experience overall fuel efficiencies of between 40 to 55 percent (actual efficiency depends on the facilities heat to power ratio).

Combined Heat and Power (known also as CHP or "cogeneration") is an integrated system located at or near the building/facility that generates utility grade electricity which satisfies at least a portion of the electrical load of the facility, and captures and recycles the waste heat from the electric generating equipment to provide useful thermal energy to the facility.

CHP implies that heat and electricity are produced simultaneously in one process. Use of combined heat and power helps to improve the overall efficiency of electricity and heat production as these systems combine electricity production technologies with heat recovery equipment. Increasing the conversion efficiency of power generation through the use of CHP helps to reduce the environmental impact of power generation. These systems can reach fuel use efficiencies of as high as 75 to 85 percent (versus the conventional energy system at approximately 40 to 55 percent).

A well designed, installed and operated CHP system provides benefits for the facility owner (end user), the electric utility, and society in general. The high efficiency attained by the CHP system provides the end user with lower overall energy costs, improved electric reliability, improved electric power quality, and improved energy security. In areas where the electric utility distribution grid is in need of expansion and/or upgrades, CHP systems can provide the electric utility with a means of deferring costly modifications to the grid.

Although the electricity generated on-site by the end user displaces the electricity purchased from the local electric utility and is seen as lost revenue by many utilities, energy efficiency and lower utility costs are in the best interest of the utility customer and should be considered as a reasonable customer option by forward-looking customer oriented utilities. Finally, society in general benefits from the high efficiencies realized by CHP systems. The high efficiencies translate to less air pollutants (lower greenhouse gas and NOx emissions) than produced from central station electric power plants.

# 14.5 Hydrogen and Electricity as Alternative Fuels

## Introduction

Since the early 20th Century, oil and the internal combustion engine have dominated transportation (Theis & Tomkin, 2015). The fortunes of oil and vehicles have been intertwined, with oil racing to meet the energy demands of the ever growing power and number of personal vehicles, vehicles driving farther in response to growing interstate highway opportunities for long distance personal travel and freight shipping, and greater personal mobility producing living patterns in far-flung suburbs that require oil and cars to function. In recent and future years, the greatest transportation growth will be in developing countries where the need and the market for transportation is growing rapidly. China has an emerging middle class that is larger than the entire population of the United States, a sign that developing countries will soon direct or strongly influence the emergence of new technologies designed to serve their needs. Beyond deploying new technologies, developing countries have a potentially large second advantage: they need not follow the same development path through outdated intermediate technologies taken by the developed world. Leapfrogging directly to the most advanced technologies avoids legacy infrastructures and long turnover times, allowing innovation and deployment on an accelerated scale.

The internal combustion engine and the vehicles it powers have made enormous engineering strides in the past half century, increasing efficiency, durability, comfort and adding such now-standard features as air conditioning, cruise control, hands-free cell phone use, and global positioning systems. Simultaneously, the automobile industry has become global, dramatically increasing competition, consumer choice and marketing reach. The most recent trend in transportation is dramatic swings in the price of oil, the lifeblood of traditional vehicles powered with internal combustion engines.

## Hydrogen as an Alternative Fuel

The traditional synergy of oil with automobiles may now be showing signs of strain. The reliance of vehicles on one fuel whose price shows strong fluctuations and whose future course is ultimately unsustainable presents long-term business challenges. Motivated by these business and sustainability concerns, the automobile industry is beginning to diversify to other fuels. Hydrogen made its debut in the early 2000s, and showed that it has the potential to power vehicles using fuel cells to produce on-board electricity for electric motors. One advantage of hydrogen is efficiency, up to 50 percent or greater for fuel cells, up to 90 percent or greater for electric motors powering the car, compared with 25 percent efficiency for an internal combustion engine. A second advantage is reduced dependence on foreign oil – hydrogen can be produced from natural gas or from entirely renewable resources such as solar decomposition of water. A third potential advantage of hydrogen is environmental – the emissions from the hydrogen car are harmless: water and a small amount of heat, though the emissions from the hydrogen production chain may significantly offset this advantage.

The vision of hydrogen cars powered by fuel cells remains strong. It must overcome significant challenges, however, before becoming practical, such as storing hydrogen on board vehicles at high densities, finding inexpensive and earth-abundant catalysts to promote the reduction of oxygen to water in fuel cells, and producing enough hydrogen from renewable sources such as solar driven water splitting to fuel the automobile industry. The hydrogen and electric energy chains for automobiles are illustrated in 14.18. Many scientists and automobile companies are exploring hydrogen as a long-term alternative to oil.

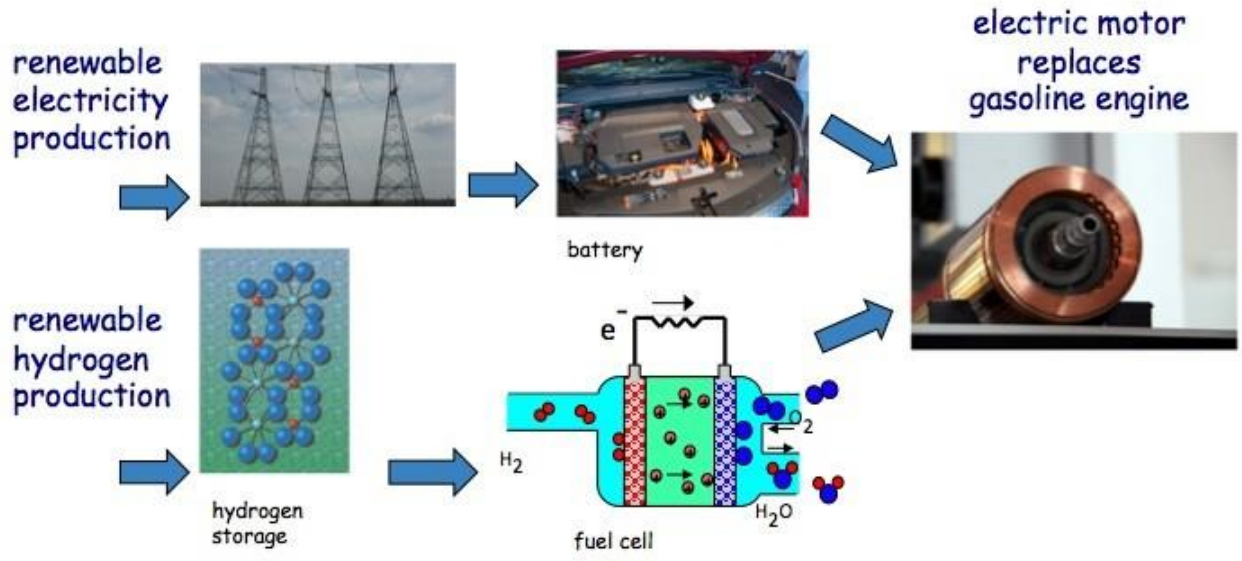


FIGURE 14.18
Electric Transportation Transportation is electrified by replacing the gasoline engine with an electric motor, powered by electricity from a battery on board the car (upper panel) or electricity from a fuel cell and hydrogen storage system on board the car (lower panel). For maximum effectiveness, both routes require renewable production of electricity or hydrogen. Source: George Crabtree using images from Rondol, skinnylawyer, Tinu Bao, U.S. Department of Energy, Office of Science

## Electricity as an Alternative Fuel

Electric cars represent a second alternative to oil for transportation, with many similarities to hydrogen (see Figure Electric Transportation). Electric vehicles are run by an electric motor, as in a fuel cell car, up to four times as efficient as a gasoline engine. The electric motor is far simpler than a gasoline engine, having only one moving part, a shaft rotating inside a stationary housing and surrounded by a coil of copper wire. Electricity comes from a battery, whose storage capacity, like that of hydrogen materials, is too small to enable long distance driving. Developing higher energy density batteries for vehicles is a major challenge for the electric car industry. The battery must be charged before driving, which can be done from the grid using excess capacity available at night, or during the day from special solar charging stations that do not add additional load to the grid. Because charging typically takes hours, a potentially attractive alternative is switching the battery out in a matter of minutes for a freshly charged one at special swapping stations. A large fleet of electric cars in the United States would require significant additional electricity, as much as 130 GW if the entire passenger and light truck fleet were converted to electricity, or 30 percent of average United States electricity usage in 2008.

The energy usage of electric cars is about a factor of four less than for gasoline cars, consistent with the higher efficiency of electric motors over internal combustion engines. Although gasoline cars vary significantly in their energy efficiency, a "typical" middle of the road value for a five-passenger car is 80kWh/100km. A typical electric car (such as the Think Ox from Norway, the Chevy Volt operating in its electric mode, or the Nissan Leaf) uses ~ 20 kWh/100km. While the energy cost of electric cars at the point of use is significantly less, one must consider the cost at the point of production, the electricity generating plant. If the vehicle's electricity comes from coal with a conversion efficiency of 33 percent, the primary energy cost is 60 kWh/100km, approaching but still smaller than that of the gasoline car. If electricity is generated by combined cycle natural gas turbines with 60 percent efficiency, the primary energy cost is 33 kWh/100km, less than half the primary energy cost for gasoline cars. These comparisons are presented in Table below.

**TABLE 14.1:** Comparison of energy use for gasoline driven and battery driven cars, for the cases of inefficient coal generation (33%) and efficient combined cycle natural gas generation (60%) of electricity. *Source: George Crabtree.*

| | **Gasoline Engine 5 passenger car** | **Battery Electric Nissan Leaf, Chevy Volt (battery mode), Think Ox** |
|---|---|---|
| **Energy use at point of use** | 80 kWh/100km | 20 kWh/100km |
| **Energy use at point of production: Coal at 33% efficiency** | | 60 kWh/100km |
| **Combined Cycle Natural Gas at 60% efficiency** | | 33 kWh/100km |

**TABLE 14.2:** Comparison of carbon emissions from gasoline driven and battery driven cars, for the cases of high emission coal generation (2.1 lb CO2/kWh), lower emission natural gas (1.3 lbCO2/kWh) and very low emission nuclear, hydro, wind or solar electricity. *Source: George Crabtree*.

| | **Gasoline Engine 5 passenger car** | **Battery Electric Nissan Leaf, Chevy Volt (battery mode), Think Ox** |
|---|---|---|
| **CO2 Emissions at point of use** | 41 lbs | ~ 0 |
| **CO2 Emissions at point of production Coal@2.1 lb CO2/kWh** | | 42 lbs |
| **Gas@1.3 lb CO2/kWh** | | 25 lbs |
| **Nuclear, hydro, wind or solar** | | <1 lb |

The carbon footprint of electric cars requires a similar calculation. For coal-fired electricity producing 2.1 lb $CO_2$/kWh, driving 100km produces 42 lbs (19 kgs) of carbon dioxide; for gas-fired electricity producing 1.3 lb $CO_2$/kWh, 100km of driving produces 26 lbs (11.7 kgs) of carbon dioxide. If electricity is produced by nuclear or renewable energy such as wind, solar or hydroelectric, no carbon dioxide is produced. For a "typical" gasoline car, 100km of driving produces 41 lbs (18.5 kgs) of carbon dioxide. Thus the carbon footprint of a "typical" electric car is, at worst equal, to that of a gasoline car and, at best, zero. Table Comparisons of Carbon Emissions summarizes the carbon footprint comparisons.

## The Hybrid Solutions

Unlike electric cars, hybrid vehicles rely only on gasoline for their power. Hybrids do, however, have a supplemental electric motor and drive system that operates only when the gasoline engine performance is weak or needs a boost: on starting from a stop, passing, or climbing hills. Conventional gasoline cars have only a single engine that must propel the car under all conditions; it must, therefore, be sized to the largest task. Under normal driving conditions the engine is larger and less efficient than it needs to be. The hybrid solves this dilemma by providing two drive trains, a gasoline engine for normal driving and an electric motor for high power needs when starting, climbing hills and passing. The engine and motor are tailored to their respective tasks, enabling each to be designed for maximum efficiency. As the electric motor is overall much more efficient, its use can raise fuel economy significantly.

The battery in hybrid cars has two functions: it drives the electric motor and also collects electrical energy from regenerative braking, converted from kinetic energy at the wheels by small generators. Regenerative braking is effective in start-stop driving, increasing efficiency up to 20 percent. Unlike gasoline engines, electric motors use no energy while standing still; hybrids therefore shut off the gasoline engine when the car comes to a stop to save the idling energy. Gasoline engines are notoriously inefficient at low speeds (hence the need for low gear ratios), so the electric motor accelerates the hybrid to ~15 mph (24 kph) before the gasoline engine restarts. Shutting the gasoline engine off while stopped increases efficiency as much as 17 percent. The energy saving features of hybrids typically lower their energy requirements from 80 kWh/100km to 50-60 kWh/100km, a significant savings. It is important to note, however, that despite a supplementary electric motor drive system, all of a hybrid's energy comes from gasoline and none from the electricity grid.

The **plug-in hybrid** differs from conventional hybrids in tapping both gasoline and the electricity grid for its energy. Most plug-in hybrids are designed to run on electricity first and on gasoline second; the gasoline engine kicks in only when the battery runs out. The plug-in hybrid is thus an electric car with a supplemental gasoline engine, the opposite of the conventional hybrid cars described above. The value of the plug-in hybrid is that it solves the "driving range anxiety" of the consumer: there are no worries about getting home safely from a trip that turns out to be longer than expected. The disadvantage of the plug-in hybrid is the additional supplemental gasoline engine technology, which adds cost and complexity to the automobile.

## The Battery Challenge

To achieve reasonable driving range, electric cars and plug-in hybrids need large batteries, one of their greatest design challenges and a potentially significant consumer barrier to widespread sales. Even with the largest practical batteries, driving range on electricity is limited, perhaps to ~100km. Designing higher energy density batteries is currently a major focus of energy research, with advances in Li-ion battery technology expected to bring significant improvements. The second potential barrier to public acceptance of electric vehicles is charging time, up to eight hours from a standard household outlet. This may suit overnight charging at home, but could be a problem for trips beyond the battery's range – with a gasoline car the driver simply fills up in a few minutes and is on his way. Novel infrastructure solutions such as battery swapping stations for long trips are under consideration.

From a sustainability perspective, the comparison of gasoline, electric, hybrid and plug-in hybrid cars is interesting. Hybrid cars take all their energy from gasoline and represent the least difference from gasoline cars. Their supplementary electric drive systems reduce gasoline usage by 30-40 percent, thus promoting conservation of a finite resource and reducing reliance on foreign oil. Electric cars, however, get all of their energy from grid electricity, a domestic energy source, completely eliminating reliance on foreign oil and use of finite oil resources. Their sustainability value is therefore higher than hybrids. Plug-in hybrids have the same potential as all electric vehicles, provided their gasoline engines are used sparingly. In terms of carbon emissions, the sustainability value of electric vehicles depends entirely on the electricity source: neutral for coal, positive for gas and highly positive for nuclear or renewable hydro, wind or solar. From an energy perspective, electric cars use a factor of four less energy than gasoline cars at the point of use, but this advantage is partially compromised by inefficiencies at the point of electricity generation. Even inefficient coal-fired electricity leaves an advantage for electric cars, and efficient gas- fired combined cycle electricity leaves electric cars more than a factor of two more energy efficient than gasoline cars.

# 14.6 Electricity Grid and Sustainability Challenges

Over the past century and a half **electricity** has emerged as a popular and versatile energy carrier (Theis & Tomkin, 2015). Today, electricity is exploited not only for its diverse end uses such as lighting, motion, refrigeration, communication and computation, but also as a primary carrier of energy. Electricity is one of two backbones of the modern energy system (liquid transportation fuels are the other), carrying high density energy over short and long distances for diverse uses. In 2009, electricity consumed the largest share of the United States' primary energy, 38 percent, with transportation a close second at 37 percent. These two sectors also accounted for the largest shares of U.S. carbon emissions, 38 percent for electricity and 33 percent for transportation.

By far most electricity is generated by combustion of fossil fuels to turn steam or gas turbines. This is the least efficient step in the energy chain, converting only 36 percent of the chemical energy in the fuel to electric energy, when averaged over the present gas and coal generation mix. It also produces all the carbon emissions of the electricity chain. Beyond production, electricity is a remarkably clean and efficient carrier. Conversion from rotary motion of the turbine and generator to electricity, the delivery of electricity through the power grid, and the conversion to motion in motors for use in industry, transportation and refrigeration can be more than 90 percent efficient. None of these steps produces greenhouse gas emissions. It is the post-production versatility, cleanliness, and efficiency of electricity that make it a prime energy carrier for the future. Electricity generation, based on relatively plentiful domestic coal and gas, is free of immediate fuel security concerns. The advent of electric cars promises to increase electricity demand and reduce dependency on foreign oil, while the growth of renewable wind and solar generation reduces carbon emissions. The primary sustainability challenges for electricity as an energy carrier are at the production step: efficiency and emission of carbon dioxide and toxins.

## The Electricity Grid: Capacity and Reliability

Beyond production, electricity faces challenges of capacity, reliability, and implementing storage and transmission required to accommodate the remoteness and variability of renewables. The largest capacity challenges are in urban areas, where 79 percent of the United States and 50 percent of the world population live. The high population density of urban areas requires a correspondingly high energy and electric power density. In the United States, 33 percent of electric power is used in the top 22 metro areas, and electricity demand is projected to grow 31 percent by 2035. This creates an "urban power bottleneck" where underground cables become saturated, hampering economic growth and the efficiencies of scale in transportation, energy use and greenhouse gas emission that come with high population density. Saturation of existing cable infrastructure requires installation of substantial new capacity, an expensive proposition for digging new underground cable tunnels.

The **reliability** of the electricity grid presents a second challenge. The United States' grid has grown continuously from origins in the early 20th Century; much of its infrastructure is based on technology and design philosophy dating from the 1950s and 1960s, when the major challenge was extending electrification to new rural and urban areas. Outside urban areas, the grid is mainly above ground, exposing it to weather and temperature extremes that cause most power outages. The response to outages is frustratingly slow and traditional – utilities are often first alerted to outages by telephoned customer complaints, and response requires sending crews to identify and repair damage, much the same as we did 50 years ago. The United States' grid reliability is significantly lower than for newer grids in Europe and Japan, where the typical customer experiences ten to 20 times less outage time than in the United States. Reliability is especially important in the digital age, when an interruption of even a fraction of a cycle can shut down a digitally controlled data center or fabrication line, requiring hours or days to restart.

Reliability issues can be addressed by implementing a smart grid with two-way communication between utility companies and customers that continuously monitors power delivery, the operational state of the delivery system, and implements demand response measures adjusting power delivered to individual customers in accordance with a previously established unique customer protocol. Such a system requires installing digital sensors that monitor power flows in the delivery system, digital decision and control technology and digital communication capability like that already standard for communication via the Internet. For customers with on-site solar generation capability, the smart grid would monitor and control selling excess power from the customer to the utility.

### Integrating Renewable Electricity on the Grid

Accommodating renewable electricity generation by wind and solar plants is among the most urgent challenges facing the grid. Leadership in promoting renewable electricity has moved from the federal to the state governments, many of which have legislated Renewable Portfolio Standards (RPS) that require 20 percent of state electricity generation to be renewable by 2020. 30 states and the District of Columbia have such requirements, the most aggressive being California with 33 percent renewable electricity required by 2020 and New York with 30 percent by 2015. To put this legal requirement in perspective, wind and solar now account for about 1.6 percent of U.S. electricity production; approximately a factor of ten short of the RPS requirements.

### Renewable Variability

The grid faces major challenges to accommodate the variability of wind and solar electricity. Without significant storage capacity, the grid must precisely balance generation to demand in real time. At present, the variability of demand controls the balancing process: demand varies by as much as a factor of two from night to day as people go through their daily routines. This predictable variability is accommodated by switching reserve generation sources in and out in response to demand variations. With renewable generation, variation can be up to 70 percent for solar electricity due to passing clouds and 100 percent for wind due to calm days, much larger than the variability of demand. At the present level of 1.6 percent wind and solar penetration, the relatively small variation in generation can be accommodated by switching in and out conventional resources to make up for wind and solar fluctuations. At the 20 percent penetration required by state Renewable Portfolio Standards, accommodating the variation in generation requires a significant increase in the conventional reserve capacity. At high penetration levels, each addition of wind or solar capacity requires a nearly equal addition of conventional capacity to provide generation when the renewables are quiescent. This double installation to insure reliability increases the cost of renewable electricity and reduces its effectiveness in lowering greenhouse gas emissions.

A major complication of renewable variation is its unpredictability. Unlike demand variability, which is reliably high in the afternoon and low at night, renewable generation depends on weather and does not follow any pattern. Anticipating weather-driven wind and solar generation variability requires more sophisticated forecasts with higher accuracy and greater confidence levels than are now available. Because today's forecasts often miss the actual performance target, additional conventional reserves must be held at the ready to cover the risk of inaccuracies, adding another increase to the cost of renewable electricity. Storage of renewable electricity offers a viable route to meeting the variable generation challenge.

### How to Transmit Electricity Over Long Distances

The final challenge for accommodating renewables is long distance transmission. Although long distance delivery is possible where special high voltage transmission lines have been located, the capacity and number of such lines is limited. The situation is much like automobile transportation before the interstate highway system was built in the 1950s. It was possible to drive coast to coast, but the driving time was long and uncertain and the route indirect. To use renewable electricity resources effectively, we must create a kind of interstate highway system for electricity.

# 14.7 Resources

## Summary

We derive our energy from a multitude of resources that have varying environmental challenges related to air and water pollution, land use, carbon dioxide emissions, resource extraction and supply, as well as related safety and health issues. Each resource needs to be evaluated within the sustainability paradigm. Coal (45 percent) and gas (23 percent) are the two primary fossil fuels for electricity production in the United States. Coal combustion produces nearly twice the carbon emissions of gas combustion. Increasing public opinion and regulatory pressure to lower carbon emissions are shifting electricity generation toward gas and away from coal. Oil for transportation and electricity generation are the two biggest users of primary energy and producers of carbon emissions in the United States. Transportation is almost completely dependent on oil and internal combustion engines for its energy. The concentration of oil in a few regions of the world creates a transportation energy security issue. Nuclear electricity offers the sustainable benefit of low carbon electricity at the cost of storing spent fuel out of the environment for up to hundreds of thousands of years. Reprocessing spent fuel offers the advantages of higher energy efficiency and reduced spent fuel storage requirements with the disadvantage of higher risk of weapons proliferation through diversion of the reprocessed fuel stream. Strong interest in renewable energy arose in the 1970s as a response to the shortage and high price of imported oil, which disrupted the orderly operation of the economies and societies of many developed countries. Today there are new motivations, including the realization that growing greenhouse gas emission accelerates global warming and threatens climate change, the growing dependence of many countries on foreign oil, and the economic drain of foreign oil payments that slow economic growth and job creation. There are three ultimate sources of all renewable and fossil energies: sunlight, the heat in the earth's core and crust, and the gravitational pull of the moon and sun on the oceans. Renewable energies are relatively recently developed and typically operate at lower efficiencies than mature fossil technologies. Like early fossil technologies, however, renewables can be expected to improve their efficiency and lower their cost over time, promoting their economic competitiveness and widespread deployment. The future deployment of renewable energies depends on many factors, including the availability of suitable land, the technological cost of conversion to electricity or other uses, the costs of competing energy technologies, and the future need for energy.

## Review Questions

1. Describe three major environmental challenges for fossil fuels in general or one in particular.
2. What are the compelling reasons to continue using coal in spite of its challenges?
3. Rate the following electricity sources for their contribution to climate change from most to least: biomass, coal, solar, wind, nuclear, natural gas, oil, geothermal, hydroelectric, MSW
4. Describe the environmental and social concerns with regard to biofuels.
5. Nuclear fuel can be used once and committed to storage or reprocessed after its initial use to recover unused nuclear fuel for re-use. What are the arguments for and against reprocessing?
6. Public acceptance is a key factor in the growth of renewable energy options. What is the public acceptance of various energy options, and how might these change over the next few decades?
7. There are many reasons to reduce consumption of oil, including an ultimately finite supply, the high cost and lost economic stimulus of payments to foreign producers, the threat of interruption of supply due to weather, natural disaster, terrorism or geopolitical decisions, and the threat of climate change due to greenhouse gas emissions. Which of these reasons are the most important? Will their relative importance change with time?

# 14.8 References

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## Supplementary Images

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# CHAPTER 15 Solid and Hazardous Waste

## Chapter Outline



FIGURE 15.1

A young boy recycling garbage in Saigon.

Etoile. (2006). Young garbage recycler in Saigon. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Young_garbage_recycler_in_Saigon.jpg

### Learning Outcomes

After studying this chapter, you should be able to:

- Understand the environmental concerns with the growing quantities and improper management of wastes being generated
- Recognize various environmental regulations governing the management of solid and hazardous wastes
- Recognize integrated waste management strategies

# 15.1 Environmental Concerns with Wastes

## Managing Growing Waste Generation

An enormous quantity of wastes are generated and disposed of annually. Alarmingly, this quantity continues to increase on an annual basis. Industries generate and dispose over 7.6 billion tons of industrial solid wastes each year, and it is estimated that over 40 million tons of this waste is hazardous (Theis & Tomkin, 2015). Nuclear wastes as well as medical wastes are also increasing in quantity every year.

Generally speaking, developed nations generate more waste than developing nations due to higher rates of consumption. Not surprisingly, the United States generates more waste per capita than any other country. High waste per capita rates are also very common throughout Europe and developed nations in Asia and Oceania. In the United States, about 243 million tons (243 trillion kg) of MSW is generated per year, which is equal to about 4.3 pounds (1.95 kg) of waste per person per day. Nearly 34 percent of MSW is recovered and recycled or composted, approximately 12 percent is burned a combustion facilities, and the remaining 54 percent is disposed of in landfills. Waste stream percentages also vary widely by region. As an example, San Francisco, California captures and recycles nearly 75 percent of its waste material, whereas Houston, Texas recycles less than three percent.

With respect to waste mitigation options, landfilling is quickly evolving into a less desirable or feasible option. Landfill capacity in the United States has been declining primarily due to (a) older existing landfills that are increasingly reaching their authorized capacity, (b) the promulgation of stricter environmental regulations has made the permitting and siting of new landfills increasingly difficult, (c) public opposition (e.g. "Not In My Backyard" or NIMBYism) delays or, in many cases, prevents the approval of new landfills or expansion of existing facilities.

## Effects of Improper Waste Disposal and Unauthorized Releases

Prior to the passage of environmental regulations, wastes were disposed improperly without due consideration of potential effects on the public health and the environment. This practice has led to numerous contaminated sites where soils and groundwater have been contaminated and pose risk to the public safety. Of more than 36,000 environmentally impacted candidate sites, there are more than 1,400 sites listed under the Superfund program National Priority List (NPL) which require immediate cleanup resulting from acute, imminent threats to environmental and human health. The USEPA identified about 2,500 additional contaminated sites that eventually require remediation. The United States Department of Defense maintains 19,000 sites, many of which have been extensively contaminated from a variety of uses and disposal practices. Further, approximately 400,000 underground storage tanks have been confirmed or are suspected to be leaking, contaminating underlying soils and groundwater. Over \$10 billion (more than \$25 billion in current dollars) were specifically allocated by CERCLA and subsequent amendments to mitigate impacted sites. However, the USEPA has estimated that the value of environmental remediation exceeds \$100 billion. Alarmingly, if past expenditures on NPL sites are extrapolated across remaining and proposed NPL sites, this total may be significantly higher – well into the trillions of dollars.

It is estimated that more than 4,700 facilities in the United States currently treat, store or dispose of hazardous wastes. Of these, about 3,700 facilities that house approximately 64,000 solid waste management units (SWMUs) may require corrective action. Accidental spillage of hazardous wastes and nuclear materials due to anthropogenic operations or natural disasters has also caused enormous environmental damage as evidenced by the events such as the facility failure in Chernobyl, Ukraine(formerly USSR) in 1986, the effects of Hurricane Katrina that devastated New Orleans, Louisiana in 2005, and the 2011 earthquake and tsunami in Fukushima, Japan.

## Adverse Impacts on Public Health

A wide variety of chemicals are present within waste materials, many of which pose a significant environmental concern. Though the leachate generated from the wastes may contain toxic chemicals, the concentrations and variety of toxic chemicals are quite small compared to hazardous waste sites. For example, explosives and radioactive wastes are primarily located at Department of Energy (DOE) sites because many of these facilities have been historically used for weapons research, fabrication, testing, and training. Organic contaminants are largely found at oil refineries, or petroleum storage sites, and inorganic and pesticide contamination usually is the result of a variety of industrial activities as well as agricultural activities. Yet, soil and groundwater contamination are not the only direct adverse effects of improper waste management activities – recent studies have also shown that greenhouse gas emissions from the wastes are significant, exacerbating global climate change.

A wide range of toxic chemicals, with an equally wide distribution of respective concentrations, is found in waste streams. These compounds may be present in concentrations that alone may pose a threat to human health or may have a synergistic/cumulative effect due to the presence of other compounds. Exposure to hazardous wastes has been linked to many types of cancer, chronic illnesses, and abnormal reproductive outcomes such as birth defects, low birth weights, and spontaneous abortions. Many studies have been performed on major toxic chemicals found at hazardous waste sites incorporating epidemiological or animal tests to determine their toxic effects.

As an example, the effects of radioactive materials are classified as **somatic** or **genetic**. The **somatic** effects may be immediate or occur over a long period of time. Immediate effects from large radiation doses often produce nausea and vomiting, and may be followed by severe blood changes, hemorrhage, infection, and death. Delayed effects include leukemia, and many types of cancer including bone, lung, and breast cancer. **Genetic** effects have been observed in which gene mutations or chromosome abnormalities result in measurable harmful effects, such as decreases in life expectancy, increased susceptibility to sickness or disease, infertility, or even death during embryonic stages of life. Because of these studies, occupational dosage limits have been recommended by the National Council on Radiation Protection. Similar studies have been completed for a wide range of potentially hazardous materials. These studies have, in turn, been used to determine safe exposure levels for numerous exposure scenarios, including those that consider occupational safety and remediation standards for a variety of land use scenarios, including residential, commercial, and industrial land uses.

## Adverse Impacts on the Environment

The chemicals found in wastes not only pose a threat to human health, but they also have profound effects on entire eco-systems. Contaminants may change the chemistry of waters and destroy aquatic life and underwater eco-systems that are depended upon by more complex species. Contaminants may also enter the food chain through plants or microbiological organisms, and higher, more evolved organisms bioaccumulate the wastes through subsequent ingestion. As the contaminants move farther up the food chain, the continued bioaccumulation results in increased contaminant mass and concentration. In many cases, toxic concentrations are reached, resulting in increased mortality of one or more species. As the populations of these species decrease, the natural inter-species balance is affected. With decreased numbers of predators or food sources, other species may be drastically affected, leading to a chain reaction that can affect a wide range of flora and fauna within a specific eco-system. As the eco-system continues to deviate from equilibrium, disastrous consequences may occur. Examples include the near extinction of the bald eagle due to persistent ingestion of DDT-impacted fish, and the depletion of oysters, crabs, and fish in Chesapeake Bay due to excessive quantities of fertilizers, toxic chemicals, farm manure wastes, and power plant emissions.

## 15.2 Waste Management Strategies

The long-recognized hierarchy of management of wastes, in order of preference consists of prevention, minimization, recycling and reuse, biological treatment, incineration, and landfill disposal (see Figure below).

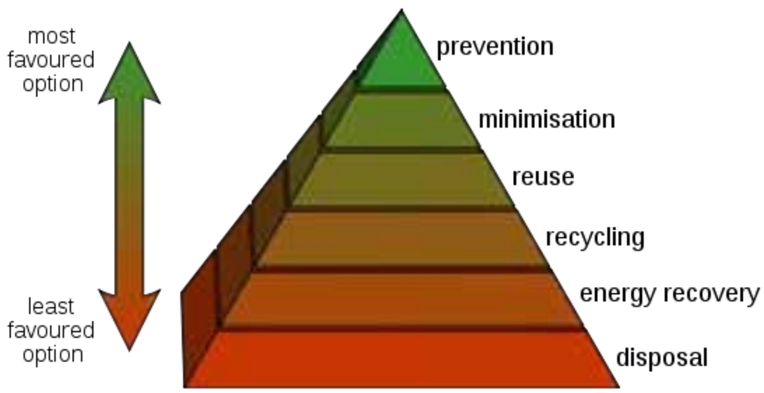


FIGURE 15.2

Hierarchy of Waste Management Figure shows the hierarchy of management of wastes in order or preference, starting with prevention as the most favorable to disposal as the least favorable option. Source: Drstuey via Wikimedia Commons

### Waste Prevention

The ideal waste management alternative is to prevent waste generation in the first place. Hence, waste prevention is a basic goal of all the waste management strategies. Numerous technologies can be employed throughout the manufacturing, use, or post-use portions of product life cycles to eliminate waste and, in turn, reduce or prevent pollution. Some representative strategies include environmentally conscious manufacturing methods that incorporate less hazardous or harmful materials, the use of modern leakage detection systems for material storage, innovative chemical neutralization techniques to reduce reactivity, or water saving technologies that reduce the need for fresh water inputs.

### Waste Minimization

In many cases, wastes cannot be outright eliminated from a variety of processes. However, numerous strategies can be implemented to reduce or minimize waste generation. Waste minimization, or source reduction, refers to the collective strategies of design and fabrication of products or services that minimize the amount of generated waste and/or reduce the toxicity of the resultant waste. Often these efforts come about from identified trends or specific products that may be causing problems in the waste stream and the subsequent steps taken to halt these problems. In industry, waste can be reduced by reusing materials, using less hazardous substitute materials, or by modifying components of design and processing. Many benefits can be realized by waste minimization or source reduction, including reduced use of natural resources and the reduction of toxicity of wastes.

Waste minimization strategies are extremely common in manufacturing applications; the savings of material use preserves resources but also saves significant manufacturing related costs. Advancements in streamlined packaging reduces material use, increased distribution efficiency reduces fuel consumption and resulting air emissions. Further, engineered building materials can often be designed with specific favorable properties that, when accounted for in overall structural design, can greatly reduce the overall mass and weight of material needed for a given structure. This reduces the need for excess material and reduces the waste associated with component fabrication.

The dry cleaning industry provides an excellent example of product substitution to reduce toxic waste generation. For decades, dry cleaners used tetrachloroethylene, or "perc" as a dry cleaning solvent. Although effective, tetrachloroethylene is a relatively toxic compound. Additionally, it is easily introduced into the environment, where it is highly recalcitrant due to its physical properties. Further, when its degradation occurs, the intermediate daughter products generated are more toxic to human health and the environment.

Because of its toxicity and impact on the environment, the dry cleaning industry has adopted new practices and increasingly utilizes less toxic replacement products, including petroleum-based compounds. Further, new emerging technologies are incorporating carbon dioxide and other relatively harmless compounds. While these substitute products have in many cases been mandated by government regulation, they have also been adopted in response to consumer demands and other market-based forces.

### Recycling and Reuse

Recycling refers to recovery of useful materials such as glass, paper, plastics, wood, and metals from the waste stream so they may be incorporated into the fabrication of new products. With greater incorporation of recycled materials, the required use of raw materials for identical applications is reduced. Recycling reduces the need of natural resource exploitation for raw materials, but it also allows waste materials to be recovered and utilized as valuable resource materials. Recycling of wastes directly conserves natural resources, reduces energy consumption and emissions generated by extraction of virgin materials and their subsequent manufacture into finished products, reduces overall energy consumption and greenhouse gas emissions that contribute to the global climate change, and reduces the incineration or landfilling of the materials that have been recycled. Moreover, recycling creates several economic benefits, including the potential to create job markets and drive growth.

Common recycled materials include paper, plastics, glass, aluminum, steel, and wood. Additionally, many construction materials can be reused, including concrete, asphalt materials, masonry, and reinforcing steel. "Green" plant-based wastes are often recovered and immediately reused for mulch or fertilizer applications. Many industries also recover various by-products and/or refine and "re-generate" solvents for reuse. Examples include copper and nickel recovery from metal finishing processes; the recovery of oils, fats, and plasticizers by solvent extraction from filter media such as activated carbon and clays; and acid recovery by spray roasting, ion exchange, or crystallization. Further, a range of used food-based oils are being recovered and utilized in "biodiesel" applications.

Numerous examples of successful recycling and reuse efforts are encountered every day. In some cases, the recycled materials are used as input materials and are heavily processed into end products. Common examples include the use of scrap paper for new paper manufacturing, or the processing of old aluminum cans into new aluminum products. In other cases, reclaimed materials undergo little or no processing prior to their re-use.

Some common examples include the use of tree waste as wood chips, or the use of brick and other fixtures into new structural construction. In any case, the success of recycling depends on effective collection and processing of recyclables, markets for reuse (e.g. manufacturing and/or applications that utilize recycled materials), and public acceptance and promotion of recycled products and applications utilizing recycled materials.

### Biological Treatment

Landfill disposal of wastes containing significant organic fractions is increasingly discouraged in many countries, including the United States. Such disposal practices are even prohibited in several European countries. Since landfilling does not provide an attractive management option, other techniques have been identified. One option is to treat waste so that biodegradable materials are degraded and the remaining inorganic waste fraction (known as residuals) can be subsequently disposed or used for a beneficial purpose.

Biodegradation of wastes can be accomplished by using aerobic composting, anaerobic digestion, or mechanical biological treatment (MBT) methods. If the organic fraction can be separated from inorganic material, aerobic composting or anaerobic digestion can be used to degrade the waste and convert it into usable compost. For example, organic wastes such as food waste, yard waste, and animal manure that consist of naturally degrading bacteria can be converted under controlled conditions into compost, which can then be utilized as natural fertilizer. Aerobic composting is accomplished by placing selected proportions of organic waste into piles, rows or vessels, either in open conditions or within closed buildings fitted with gas collection and treatment systems. During the process, bulking agents such as wood chips are added to the waste material to enhance the aerobic degradation of organic materials. Finally, the material is allowed to stabilize and mature during a curing process where pathogens are concurrently destroyed. The end-products of the composting process include carbon dioxide, water, and the usable compost material.

Compost material may be used in a variety of applications. In addition to its use as a soil amendment for plant cultivation, compost can be used remediate soils, groundwater, and stormwater. Composting can be labor-intensive, and the quality of the compost is heavily dependent on proper control of the composting process. Inadequate control of the operating conditions can result in compost that is unsuitable for beneficial applications. Nevertheless, composting is becoming increasingly popular; composting diverted 82 million tons of waste material away the landfill waste stream in 2009, increased from 15 million tons in 1980. This diversion also prevented the release of approximately 178 million metric tons of carbon dioxide in 2009 – an amount equivalent to the yearly carbon dioxide emissions of 33 million automobiles.

In some cases, aerobic processes are not feasible. As an alternative, anaerobic processes may be utilized. Anaerobic digestion consists of degrading mixed or sorted organic wastes in vessels under anaerobic conditions. The anaerobic degradation process produces a combination of methane and carbon dioxide (biogas) and residuals (biosolids). Biogas can be used for heating and electricity production, while residuals can be used as fertilizers and soil amendments. Anaerobic digestion is a preferred degradation for wet wastes as compared to the preference of composting for dry wastes. The advantage of anaerobic digestion is biogas collection; this collection and subsequent beneficial utilization makes it a preferred alternative to landfill disposal of wastes. Also, waste is degraded faster through anaerobic digestion as compared to landfill disposal.

Another waste treatment alternative, mechanical biological treatment (MBT), is not common in the United States. However, this alternative is widely used in Europe. During implementation of this method, waste material is subjected to a combination of mechanical and biological operations that reduce volume through the degradation of organic fractions in the waste. Mechanical operations such as sorting, shredding, and crushing prepare the waste for subsequent biological treatment, consisting of either aerobic composting or anaerobic digestion. Following the biological processes, the reduced waste mass may be subjected to incineration.

### Incineration

Waste degradation not only produces useful solid end-products (such as compost), degradation by-products can also be used as a beneficial energy source. As discussed above, anaerobic digestion of waste can generate biogas, which can be captured and incorporated into electricity generation. Alternatively, waste can be directly incinerated to produce energy. Incineration consists of waste combustion at very high temperatures to produce electrical energy. The byproduct of incineration is ash, which requires proper characterization prior to disposal, or in some cases, beneficial re-use. It is widely used in developed countries due to landfill space limitations. It is estimated that about 130 million tons of waste are annually combusted in more than 600 plants in 35 countries. Further, incineration is often used to effectively mitigate hazardous wastes such as chlorinated hydrocarbons, oils, solvents, medical wastes, and pesticides.

TABLE 15.1:

| Pros of Incinerators | Cons of Incinerators |
|---|---|
| The incinerated waste is turned into energy. | The fly ash (airborne particles) has high levels of toxic chemicals, including dioxin, cadmium and lead. |
| The volume of waste is reduced. | The initial construction costs are high. |

Despite the advantages, incineration is often viewed negatively because of high initial construction costs, and emissions of ash, which is toxic (see Table 15.1). Currently, many ’next generation" systems are being researched and developed, and the USEPA is developing new regulations to carefully monitor incinerator air emissions under the Clean Air Act.

### Landfill Disposal

Despite advances in reuse and recycling, landfill disposal remains the primary waste disposal method in the United States. As previously mentioned, the rate of MSW generation continues to increase, but overall landfill capacity is decreasing. New regulations concerning proper waste disposal and the use of innovative liner systems to minimize the potential of groundwater contamination from leachate infiltration and migration have resulted in a substantial increase in the costs of landfill disposal. Also, public opposition to landfills continues to grow, partially inspired by memories of historic uncontrolled dumping practices the resulting undesirable side effects of uncontrolled vectors, contaminated groundwater, unmitigated odors, and subsequent diminished property values.

Landfills can be designed and permitted to accept hazardous wastes in accordance with RCRA Subtitle C regulations, or they may be designed and permitted to accept municipal solid waste in accordance with RCRA Subtitle D regulations. Regardless of their waste designation, landfills are engineered structures consisting of bottom and side liner systems, leachate collection and removal systems, final cover systems, gas collection and removal systems, and groundwater monitoring systems. An extensive permitting process is required for siting, designing and operating landfills. Post-closure monitoring of landfills is also typically required for at least 30 years. Because of their design, wastes within landfills are degraded anaerobically. During degradation, biogas is produced and collected. The collection systems prevent uncontrolled subsurface gas migration and reduce the potential for an explosive condition. The captured gas is often used in cogeneration facilities for heating or electricity generation. Further, upon closure, many landfills undergo "land recycling" and redeveloped as golf courses, recreational parks, and other beneficial uses.

Wastes commonly exist in a dry condition within landfills, and as a result, the rate of waste degradation is commonly very slow. These slow degradation rates are coupled with slow rates of degradation-induced settlement, which can in turn complicate or reduce the potential for beneficial land re-use at the surface. Recently, the concept of bioreactor landfills has emerged, which involves recirculation of leachate and/or injection of selected liquids to increase the moisture in the waste, which in turn induces rapid degradation. The increased rates of degradation increase the rate of biogas production, which increases the potential of beneficial energy production from biogas capture and utilization.

# 15.3 Waste Policies

## Regulatory Framework in the United States

During the course of the 20th century, especially following World War II, the United States experienced unprecedented economic growth (Theis & Tomkin, 2015). Much of the growth was fueled by rapid and increasingly complex industrialization. With advances in manufacturing and chemical applications also came increases in the volume, and in many cases the toxicity, of generated wastes. Furthermore, few if any controls or regulations were in place with respect to the handling of toxic materials or the disposal of waste products. Continued industrial activity led to several high-profile examples of detrimental consequences to the environment resulting from these uncontrolled activities. Finally, several forms of intervention, both in the form of government regulation and citizen action, occurred in the early 1970s.

Ultimately, several regulations were promulgated on the state and federal levels to ensure the safety of public health and the environment. With respect to waste materials, the Resource Conservation and Recovery Act (RCRA), enacted by the United States Congress, first in 1976 and then amended in 1984, provides a comprehensive framework for the proper management of hazardous and non-hazardous solid wastes in the United States. RCRA stipulates broad and general legal objectives while mandating the United States Environmental Protection Agency (USEPA) to develop specific regulations to implement and enforce the law. States and local governments can either adopt the federal regulations, or they may develop and enforce more stringent regulations than those specified in RCRA. Similar regulations have been developed or are being developed worldwide to manage wastes in a similar manner in other countries.

The broad goals of RCRA include: (1) the protection of public health and the environment from the hazards of waste disposal; (2) the conservation of energy and natural resources; (3) the reduction or elimination of waste; and (4) the assurance that wastes are managed in an environmentally-sound manner (e.g. the remediation of waste which may have spilled, leaked, or been improperly disposed). It should be noted here that the RCRA focuses only on active and future facilities and does not address abandoned or historical sites. These types of environmentally impacted sites are managed under a different regulatory framework, known as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, or more commonly known as "Superfund."

### Solid Waste Regulations

RCRA defines solid waste as any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities. In general, solid waste can be categorized as either **non-hazardous waste** or **hazardous waste**.

Non-hazardous solid waste can be trash or garbage generated from residential households, offices and other sources. Generally, these materials are classified as municipal solid waste (MSW). Alternatively, non-hazardous materials that result from the production of goods and products by various industries (e.g. coal combustion residues, mining wastes, cement kiln dust), are collectively known as industrial solid waste. Because they are classified as non-hazardous material, many components of municipal solid waste and industrial waste have potential for recycling and re-use. Significant efforts are underway by both government agencies and industry to advance these objectives.

Hazardous waste, generated by many industries and businesses (e.g. dry cleaners and auto repair shops), is constituted of materials that are dangerous or potentially harmful to human health and the environment. Waste is classified as hazardous if it exhibits at least one of these four characteristics:

- Ignitability which refers to creation of fires under certain conditions; including materials that are spontaneously combustible or those that have a flash point less than 140 $^{0}$F.
- Corrosivity, which refers to capability to corrode metal containers; including materials with a pH less than or equal to 2 or greater than or equal to 12.5.
- Reactivity, which refers to materials susceptible to unstable conditions such as explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water under normal conditions.
- Toxicity, which refers to substances that can induce harmful or fatal effects when ingested or absorbed, or inhaled.

### Radioactive Waste Regulations

Although non-hazardous waste and hazardous waste are regulated by RCRA, nuclear or radioactive waste is regulated in accordance with the Atomic Energy Act of 1954 by the Nuclear Regulatory Commission (NRC) in the United States.

Radioactive wastes are characterized according to four categories: (1) High-level waste (HLW), (2) Transuranic waste (TRU), (3) Low-level waste (LLW), and (4) Mill tailings. Various radioactive wastes decay at different rates, but health and environmental dangers due to radiation may persist for hundreds or thousands of years.

High-level waste is typically liquid or solid waste that results from government defense related activities or from nuclear power plants and spent fuel assemblies. These wastes are extremely dangerous due to their heavy concentrations of radionuclides, and humans must not come into contact with them.

Transuranic waste mainly results from the reprocessing of spent nuclear fuels and from the fabrication of nuclear weapons for defense projects. They are characterized by moderately penetrating radiation and a decay time of approximately twenty years until safe radionuclide levels are achieved. Following the passage of a reprocessing ban in 1977, most of this waste generation ended. Even though the ban was lifted in 1981, Transuranic waste continues to be rare because reprocessing of nuclear fuel is expensive. Further, because the extracted plutonium may be used to manufacture nuclear weapons, political and social pressures minimize these activities.

Low level wastes include much of the remainder of radioactive waste materials. They constitute over 80 percent of the volume of all nuclear wastes, but only about two percent of total radioactivity. Sources of Low level wastes include all of the previously cited sources of High-level waste and Transuranic waste, plus wastes generated by hospitals, industrial plants, universities, and commercial laboratories. Low level waste is much less dangerous than High-level waste, and NRC regulations allow some very low-level wastes to be released to the environment. Low level wastes may also be stored or buried until the isotopes decay to levels low enough such that it may be disposed of as non-hazardous waste. Low level wastes disposal is managed at the state level, but requirements for operation and disposal are established by the USEPA and NRC. The Occupational Health and Safety Administration (OSHA) is the agency in charge of setting the standards for workers that are exposed to radioactive materials.

## International Regulatory Framework

### The 1992 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal first came into force in 1992. The Convention puts an onus on exporting countries to ensure that hazardous wastes are managed in an environmentally sound manner in the country of import.

The Basel Convention places obligations on countries that are party to the Convention. 151 Countries have ratified the Basel Convention as at December 2002. These have obligations to:

- Minimize generation of hazardous waste;

- Ensure adequate disposal facilities are available;
- Control and reduce international movements of hazardous waste;
- Ensure environmentally sound management of wastes; and
- Prevent and punish illegal traffic.

### The 1995 Waigani Convention

The Basel Convention establishes a global control system for hazardous wastes being shipped from one country to another. States which are Parties to the Convention must not trade in hazardous wastes with non-Parties but an exception to this is provided for in Article 11 of the Convention, whereby Parties may enter into agreements or arrangements either with other Parties or with non-Parties.

These agreements or arrangements can also set out controls which are different from those prescribed by the Convention itself, provided such controls do not reduce the level of environmental protection intended by the Convention.

The **Waigani Convention** to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific Region) is one such agreement which is entered into force in October 2001.

The main effect of this Convention is to ban the import of all hazardous and radioactive wastes into South Pacific Forum Island Countries. It also enables Australia to receive hazardous wastes exported from South Pacific Forum Island countries which are not Parties to the Basel Convention. There are 24 countries within the coverage area of the Waigani Convention.

As at December 2002, ten parties had ratified the Waigani Convention. These were Australia, Cook Islands, Federated States of Micronesia, Kirribati, New Zealand, Papua New Guinea, Samoa, Solomon Islands, Tuvalu and Vanuatu.

## 15.4 Case Study: Electronic Waste and Extended Producer Responsibility

Electronic waste, commonly known as e-waste, refers to discarded electronic products such as televisions, computers and computer peripherals (e.g. monitors, keyboards, disk drives, and printers), telephones and cellular phones, audio and video equipment, video cameras, fax and copy machines, video game consoles, and others (see Figure 15.3).

FIGURE 15.3 Electronic Waste Photograph shows many computers piled up in a parking lot as waste. Source: Bluedisk via Wikimedia Commons

In the United States, it is estimated that about 3 million tons of e-waste are generated each year (Theis & Tomkin, 2015). This waste quantity includes approximately 27 million units of televisions, 205 million units of computer products, and 140 million units of cell phones. Less than 15 to 20 percent of the e-waste is recycled or refurbished; the remaining percentage is commonly disposed of in landfills and/or incinerated. It should be noted that e-waste constitutes less than 4 percent of total solid waste generated in the United States. However, with tremendous growth in technological advancements in the electronics industry, many electronic products are becoming obsolete quickly, thus increasing the production of e-waste at a very rapid rate. The quantities of e-waste generated are also increasing rapidly in other countries such as India and China due to high demand for computers and cell phones.

In addition to the growing quantity of e-waste, the hazardous content of e-waste is a major environmental concern and poses risks to the environment if these wastes are improperly managed once they have reached the end of their useful life. Many e-waste components consist of toxic substances, including heavy metals such as lead, copper, zinc, cadmium, and mercury as well as organic contaminants, such as flame retardants (polybrominated biphenyls and polybrominated diphenylethers). The release of these substances into the environment and subsequent human exposure can lead to serious health and pollution issues. Concerns have also been raised with regards to the release of toxic constituents of e-waste into the environment if landfilling and/or incineration options are used to manage the e-waste.

Various regulatory and voluntary programs have been instituted to promote reuse, recycling and safe disposal of bulk e-waste. Reuse and refurbishing has been promoted to reduce raw material use energy consumption, and water consumption associated with the manufacture of new products. Recycling and recovery of elements such as lead, copper, gold, silver and platinum can yield valuable resources which otherwise may cause pollution if improperly released into the environment. The recycling and recovery operations have to be conducted with extreme care, as the exposure of e-waste components can result in adverse health impacts to the workers performing these operations. For economic reasons, recycled e-waste is often exported to other countries for recovery operations. However, lax regulatory environments in many of these countries can lead to unsafe practices or improper disposal of bulk residual e-waste, which in turn can adversely affect vulnerable populations.

In the United States, there are no specific federal laws dealing with e-waste, but many states have recently developed e-waste regulations that promote environmentally sound management. For example, the State of California passed the Electronic Waste Recycling Act in 2003 to foster recycling, reuse, and environmentally sound disposal of residual bulk e-waste. Yet, in spite of recent regulations and advances in reuse, recycling and proper disposal practices, additional sustainable strategies to manage e-waste are urgently needed.

One sustainable strategy used to manage e-waste is extended producer responsibility (EPR), also known as product stewardship. This concept holds manufacturers liable for the entire life-cycle costs associated with the electronic products, including disposal costs, and encourages the use of environmental-friendly manufacturing processes and products. Manufacturers can pursue EPR in multiple ways, including reuse/refurbishing, buy-back, recycling, and energy production or beneficial reuse applications. Life-cycle assessment and life-cycle cost methodologies may be used to compare the environmental impacts of these different waste management options. Incentives or financial support is also provided by some government and/or regulatory agencies to promote EPR. The use of non-toxic and easily recyclable materials in product fabrication is a major component of any EPR strategy. A growing number of companies (e.g. Dell, Sony, HP) are embracing EPR with various initiatives towards achieving sustainable e-waste management.

EPR is a preferred strategy because the manufacturer bears a financial and legal responsibility for their products; hence, they have an incentive to incorporate green design and manufacturing practices that incorporate easily recyclable and less toxic material components while producing electronics with longer product lives. One obvious disadvantage of EPR is the higher manufacturing cost, which leads to increased cost of electronics to consumers.

There is no specific federal law requiring EPR for electronics, but the United States Environmental Protection Agency (USEPA) undertook several initiatives to promote EPR to achieve the following goals: (1) foster environmentally conscious design and manufacturing, (2) increase purchasing and use of more environmentally sustainable electronics, and (3) increase safe, environmentally sound reuse and recycling of used electronics. To achieve these goals, USEPA has been engaged in various activities, including the promotion of environmental considerations in product design, the development of evaluation tools for environmental attributes of electronic products, the encouragement of recycling (or *e*-cycling), and the support of programs to reduce e-waste, among others. More than 20 states in the United States and various organizations worldwide have already developed laws and/or policies requiring EPR in some form when dealing with electronic products. For instance, the New York State Wireless esc ling Act emphasizes that authorized retailers and service providers should be compelled to participate in take-back programs, thus allowing increased recycling and reuse of e-waste. Similarly, Maine is the first U.S. state to adopt a household e-waste law with EPR.

In Illinois, Electronic Products Recycling & Reuse Act requires the electronic manufacturers to participate in the management of discarded and unwanted electronic products from residences. The Illinois EPA has also compiled- waste collection site locations where the residents can give away their discarded electronic products at no charge. Furthermore, USEPA compiled a list of local programs and manufacturers/retailers that can help consumers to properly donate or recycle e-waste.

Overall, the growing quantities and environmental hazards associated with electronic waste are of major concern to waste management professionals worldwide. Current management strategies, including recycling and refurbishing, have not been successful. As a result, EPR regulations are rapidly evolving throughout the world to promote sustainable management of e-waste. However, neither a consistent framework nor assessment tools to evaluate EPR have been fully developed.

## 15.5 Resources

### Summary

Many wastes, such as high-level radioactive wastes, will remain dangerous for thousands of years, and even MSW can produce dangerous leachate that could devastate an entire eco-system if allowed infiltrate into and migrate within groundwater. In order to protect human health and the environment, environmental professionals must deal with problems associated with increased generation of waste materials. The solution must focus on both reducing the sources of wastes as well as the safe disposal of wastes. It is, therefore, extremely important to know the sources, classifications, chemical compositions, and physical characteristics of wastes, and to understand the strategies for managing them. Waste management practices vary not only from country to country, but they also vary based on the type and composition of waste. Regardless of the geographical setting of the type of waste that needs to be managed, the governing principle in the development of any waste management plan is resource conservation. Natural resource and energy conservation is achieved by managing materials more efficiently. Reduction, reuse, and recycling are primary strategies for effective reduction of waste quantities. Further, proper waste management decisions have increasing importance, as the consequences of these decisions have broader implications with respect to greenhouse gas emissions and global climate change. As a result, several public and private partnership programs are under development with the goal of waste reduction through the adoption of new and innovative waste management technologies. Because waste is an inevitable by-product of civilization, the successful implementation of these initiatives will have a direct effect on the enhanced quality of life for societies worldwide.

### Review Questions

1. How is hazardous waste defined according to the Resource Conservation and Recovery Act (RCRA)? In your opinion, is this definition appropriate? Explain.
2. Explain specific characteristics of radioactive and medical wastes that make their management more problematic than MSW.
3. Compare and contrast environmental concerns with wastes in a rural versus urban setting.
4. What are the pros and cons of various waste management strategies? Do you agree or disagree with the general waste management hierarchy?
5. Explain the advantages and disadvantages of biological treatment and incineration of wastes.

# 15.6 References

Theis, T. & Tomkin, J. (Eds.). (2015). *Sustainability: A comprehensive foundation*. Retrieved from http://cnx.org/contents/1741effd-9cda-4b2b-a91e-003e6f587263@43.5. Available under Creative Commons Attribution 4.0 International License. (CC BY 4.0). Modified from original.

## Supplementary Images

Etoile. (2006). Young garbage recycler in Saigon. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Young_garbage_recycler_in_Saigon.jpg

# CHAPTER 16 Environmental Economics and Policies

## Chapter Outline



FIGURE 16.1

Cuyahoga River in Peninsula, OH. Thanks to the Clear Water Act, billions of pounds of pollution have been kept out of the river.

## Learning Outcomes

After studying this chapter, you should be able to:

- Define cost-benefit analysis.
- Explain why discounting is controversial.
- Explain the concept of external cost.
- Know what incentive policies are, what they do, and what their strengths and weaknesses are.
- List major international and US environmental laws and regulations.

# 16.1 Environmental Economics

Environmental and natural resource economists study the tradeoffs associated with one of the most important scarce resources we have—nature. Economists mean something very specific when they use the word **efficient** (Theis & Tomkin, 2015). In general, an allocation is efficient if it maximizes social well-being, or **welfare**. Traditional economics defines welfare as total net benefits—the difference between the total benefits all people in society get from market goods and services and the total costs of producing those things. Environmental economists enhance the definition of welfare. The values of environmental goods like wildlife count on the "benefit" side of net benefits and damages to environmental quality from production and consumptive processes count as costs.

Under ideal circumstances, market outcomes are efficient. In perfect markets for regular goods, goods are produced at the point where the cost to society of producing the last unit, **the marginal cost**, is just equal to the amount a consumer is willing to pay for that last unit, the **marginal benefit**, which means that the net benefits in the market are maximized. Regular goods are supplied by industry such that supply is equivalent to the marginal production costs to the firms, and they are demanded by consumers in such a way that we can read the marginal benefit to consumers off the demand curve; when the market equilibrates at a price that causes quantity demanded to equal quantity supplied at that price, it is also true that marginal benefit equals marginal cost.

Even non-renewable resources such as oil would be used efficiently by a well-functioning market. It is socially efficient to use a non-renewable resource over time such that the price rises at the same rate as the rate of interest. Increasing scarcity pushes the price up, which stimulates efforts to use less of the resource and to invest in research to make "backstop" alternatives more cost-effective. Eventually, the cost of the resource rises to the point where the backstop technology is competitive, and the market switches from the non-renewable resource to the backstop. We see this with copper; high prices of non-renewable copper trigger substitution to other materials, like fiber optics for telephone cables and plastics for pipes. We would surely see the same thing happen with fossil fuels; if prices are allowed to rise with scarcity, firms have more incentives to engage in research that lowers the cost of backstop technologies like solar and wind power, and we will eventually just switch. Unfortunately, many conditions can lead to **market failure** such that the market outcome does not maximize social welfare. The extent to which net benefits fall short of their potential is called **deadweight loss**. Deadweight loss can exist when not enough of a good is produced, or too much of a good is produced, or production is not done in the most cost-effective (least expensive) way possible, where costs include environmental damages. Some types of market failures (and thus deadweight loss) are extremely common in environmental settings.

## Externalities

In a market economy, people and companies make choices to balance the costs and benefits that accrue to them (Theis & Tomkin, 2015). 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 side effects because it is only concerned with buyers and sellers, not with the well-being of the environment. When this is true economists say there are externalities, and individual actions do not typically yield efficient outcomes. A **negative externality** is a cost associated with an action that is not borne by the person who chooses to take that action.

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

For example, exhaust pollutants from automobiles adversely affect the health and welfare of the human population. However, oil companies consider their cost of producing gasoline to include only their exploration and production costs. Therefore, any measures to reduce exhaust pollutants represent an external cost. The government tries to help reduce the problem of exhaust pollutants by setting emissions and fuel-efficiency standards for automobiles. It also collects a gasoline tax that increases the final price of gasoline, which may encourage people to drive less. Sometimes, pollution results from the production process because no property rights are involved. For example, if a paper manufacturer dumps waste in a privately owned pond, the landowner generally takes legal action against the paper firm, claiming compensation for a specific loss in property value caused by the industrial pollution. In contrast, the air and most waterways are not owned by individuals or businesses, but instead are considered to be public goods. Because no property rights are involved the generation of pollution does not affect supply and demand.

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

Other example of negative externalities in environmental settings include:

- Companies that spill oil into the ocean do not bear the full costs of the resulting harm to the marine environment, which include everything from degraded commercial fisheries to reduced endangered sea turtle populations).
- Commuters generate emissions of air pollution, which lowers the ambient quality of the air in areas they pass through and causes health problems for other people.
- Developers who build houses in bucolic exurban settings cause habitat fragmentation and biodiversity loss, inflicting a cost on the public at large.

A **positive externality** is a benefit associated with an action that is not borne by the person who chooses to take that action. Positive externalities exist in the world of actions and products that affect the environment including:

- A homeowner who installs a rain barrel to collect unchlorinated rainwater for her garden also improves stream habitat in her watershed by reducing stormwater runoff.
- A delivery company that re-optimizes its routing system to cut fuel costs also improves local air quality by cutting its vehicle air pollution emissions.
- A farmer who plants winter cover crops to increase the productivity of his soil will also improve water quality in local streams by reducing erosion.

## Public Goods and Common-Pool Resources

Market outcomes are almost never efficient in two broad kinds of cases: public goods and common-pool resources. The market failures in these settings are related to the problems we saw with externalities. A pure public good is defined as being nonexclusive and nonrival in consumption. If something is nonexclusive, people cannot be prevented from enjoying its benefits. A private house is exclusive because doors, windows, and an alarm system can be used to keep nonowners out. A lighthouse, on the other hand, is non-exclusive because ships at sea cannot be prevented from seeing its light. A good that is nonrival in consumption has a marginal benefit that does not decline with the number of people who consume it. A sandwich is completely rival in consumption: if I eat it, you cannot. On the other hand, the beauty of a fireworks display is completely unaffected by the number of people who look at it. Some elements of the environment are pure public goods: Clean air in a city provides health benefits to everyone, and people cannot be prevented from breathing.

The efficient amount of a public good is still where social marginal benefit equals the marginal cost of provision. However, the social marginal benefit of one unit of a public good is often very large because many people in society can benefit from that unit simultaneously. One lighthouse prevents all the ships in an area from running aground in a storm. In contrast, the social marginal benefit of a sandwich is just the marginal benefit gained by the one person who gets to eat it. Society could figure out the efficient amount of a public good to provide—say, how much to spend on cleaner cars that reduce air pollution in a city. Unfortunately, private individuals acting on their own are unlikely to provide the efficient amount of the public good because of the free rider problem. If my neighbors reduce pollution by buying clean electric cars or commuting via train, I can benefit from that cleaner air; thus, I might try to avoid doing anything costly myself in hopes that everyone else will clean the air for me. Evidence suggests that people do not behave entirely like free riders – they contribute voluntarily to environmental groups and public radio stations. However, the levels of public-good provision generated by a free market are lower than would be efficient. The ozone layer is too thin; the air is too dirty. Public goods have big multilateral positive externality problems.

In contrast, a common-pool resource (also sometimes called an open-access resource) suffers from big multilateral negative externality problems. This situation is sometimes called the "**tragedy of the commons**." Like public goods, common-pool resources are non-excludable. However, they are highly rival in use. Many natural resources have common-pool features: Water in a river can be removed by anyone near it for irrigation, drinking, or industrial use; the more water one set of users removes, the less water there is available for others. Swordfish in the ocean can be caught by anyone with the right boat and gear, and the more fish are caught by one fleet of boats, the fewer remain for other fishers to catch. Old growth timber in a developing country can be cut down by many people, and slow re-growth means that the more timber one person cuts the less there is available for others. One person's use of a common-pool resource has negative effects on all the other users. Thus, these resources are prone to overexploitation. One person in Indonesia might want to try to harvest tropical hardwood timber slowly and sustainably, but the trees they forebear from cutting today might be cut down by someone else tomorrow. The difficulty of managing common-pool resources is evident around the world in rapid rates of tropical deforestation, dangerous over-harvesting of fisheries, and battles fought over mighty rivers that have been reduced to dirty trickles. The tragedy of the commons occurs most often when the value of the resource is great, the number of users is large, and the users do not have social ties to one another, but common-pool resources are not always abused.

## Incentive Policies

Incentive policies try to make use of market forces for what they do best—allocating resources cost-effectively within an economy—while correcting the market failures associated with externalities, public goods, and common pool resources.

### Taxing Pollution

One way to "internalize" some of the external costs of pollution is for the government to tax pollution (University of California College Prep, 2012). 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. Thus, if we think the social cost of ton of carbon dioxide (because of its contribution to climate change) is $20, then we could charge a tax of $20 per ton of carbon dioxide emitted. The easiest way to do this would be to have a tax on fossil fuels according to the amount of carbon dioxide that will be emitted when they are burned.

If a price is placed on carbon dioxide, all agents would have an incentive to reduce their carbon dioxide emissions to the point where the cost to them of reducing one more unit (their marginal abatement cost) is equal to the per unit tax. Therefore, several good things happen. All carbon dioxide sources are abating to the same marginal abatement cost, so the total abatement is accomplished in the most cost-effective way possible. Furthermore, total emissions in the economy overall will go down to the socially efficient level. Firms and individuals have very broad incentives to change things to reduce carbon dioxide emissions—reduce output and consumption, increase energy efficiency, switch to low carbon fuels—and strong incentives to figure out how to innovate so those changes are less costly. Finally, the government could use the revenue it collects from the tax to correct any inequities in the distribution of the program's cost among people in the economy or to reduce other taxes on things like income.

While taxes on externality-generating activities have many good features, they also have several drawbacks and limitations. First, while an externality tax can yield the efficient outcome (where costs and benefits are balanced for the economy as a whole), that only happens if policy makers know enough about the value of the externality to set the tax at the right level. If the tax is too low, we will have too much of the harmful activity; if the tax is too high, the activity will be excessively suppressed. Second, even if we are able to design a perfect externality tax in theory, such a policy can be difficult to enforce. The enforcement agency needs to be able to measure the total quantity of the thing being taxed. In some cases that is easy—in the case of carbon dioxide for example, the particular fixed link between carbon dioxide emissions and quantities of fossil fuels burned means that through the easy task of measuring fossil fuel consumption we can measure the vast majority of carbon dioxide emissions. However, many externality-causing activities or materials are difficult to measure in total. Nitrogen pollution flows into streams as a result of fertilizer applications on suburban lawns, but it is impossible actually to measure the total flow of nitrogen from a single lawn over the course of a year so that one could tax the homeowner for that flow. Third, externality taxes face strong political opposition from companies and individuals who don't want to pay the tax. Even if the government uses the tax revenues to do good things or to reduce other tax rates, the group that disproportionately pays the tax has an incentive to lobby heavily against such a policy. This phenomenon is at least partly responsible for the fact that there are no examples of pollution taxes in the U.S. Instead, U.S. policy makers have implemented mirror-image subsidy policies, giving subsidies for activities that reduce negative externalities rather than taxing activities that cause those externalities.

### Tradable Permits

Another major type of incentive policy is a tradable permits scheme. Tradable permits are actually very similar to externality taxes, but they can have important differences. These policies are colloquially known as "cap and trade". If we know the efficient amount of the activity to have (e.g., number of tons of pollution, amount of timber to be logged) the policy maker can set a cap on the total amount of the activity equal to the efficient amount. Permits are created such that each permit grants the holder permission for one unit of the activity. The government distributes these permits to the affected individuals or firms, and gives them permission to sell (trade) them to one another. In order to be in compliance with the policy (and avoid punishment, such as heavy fines) all agents must hold enough permits to cover their total activity for the time period. The government doesn't set a price for the activity in question, but the permit market yields a price for the permits that gives all the market participants strong incentives to reduce their externality-generating activities, to make cost-effective trades with other participants, and to innovate to find cheaper ways to be in compliance. Tradable permit policies have been used in several environmental and natural resource policies. The European Union used a tradable permit market as part of its policy to reduce carbon dioxide emissions under the Kyoto protocol. Individual tradable quotas for fish in fisheries of Alaska and New Zealand have been used to rationalize fishing activity and keep total catches down to efficient and sustainable levels. Economists do think differently about costs than engineers or other physical scientists, and several key insights about the economics of cost evaluation are important for policy analysis. Viewed through an inverse lens, all these ideas are important for benefit estimation as well.

## Discounting and Cost Benefit Analysis

Economists have developed a tool for comparing net benefits at different points in time called **discounting** (University of California College Prep, 2012). Discounting converts a quantity of money received at some point in the future into a quantity that can be directly compared to money received today, controlling for the time preference. A particular cost or benefit is worth less in present value terms the farther into the future it accrues and the higher the value of the discount rate. These fundamental features of discounting create controversy over the use of discounting because they make projects to deal with long- term environmental problems seem unappealing. The most pressing example of such controversy swirls around analysis of climate-change policy. Climate-change mitigation policies typically incur immediate economic costs (e.g. switching from fossil fuels to more expensive forms of energy) to prevent environmental damages from climate change several decades in the future. Discounting lowers the present value of the future improved environment while leaving the present value of current costs largely unchanged. **Cost-benefit analysis** is just that: analysis of the costs and benefits of a proposed policy or project. To carry out a cost-benefit analysis, one carefully specifies the change to be evaluated, measures the costs and benefits of that change for all years that will be affected by the change, finds the totals of the presented discounted values of those costs and benefits, and compares them. Some studies look at the difference between the benefits and the costs (the net present value), while others look at the ratio of benefits to costs. A "good" project is one with a net present value greater than zero and a benefit/cost ratio greater than one. The result of a cost-benefit analysis depends on a large number of choices and assumptions. What discount rate is assumed? What is the status quo counterfactual against which the policy is evaluated? How are the physical effects of the policy being modeled? Which costs and benefits are included in the analysis—are non-use benefits left out? Good cost-benefit analyses should make all their assumptions clear and transparent.

Cost-benefit analysis gives us a rough sense of whether or not a project is a good idea. However, it has many limitations. Here we discuss several other measures of whether a project is desirable. Economists use all these criteria and more when evaluating whether a policy is the right approach for solving a problem with externalities, public goods, and common-pool resources.

*Efficiency*

A policy is efficient if it maximizes the net benefits society could get from an action of that kind. Such efficiency will occur when the marginal benefits of the policy are equal to its marginal costs. Sometimes a cost-benefit analysis will try to estimate the total costs and benefits for several policies with different degrees of stringency to try to see if one is better than the others. However, only information about the marginal benefit and marginal cost curves will ensure that the analyst has found the efficient policy. Unfortunately, such information is often very hard to find or estimate.

*Cost Effectiveness*

It can be particularly difficult to estimate the benefits of environmental policy, and benefit estimates are necessary for finding efficient policies. Sometimes policy goals are just set through political processes—reducing sulfur dioxide emissions by 10 million tons below 1980 levels in the Clean Air Act acid rain provisions, cutting carbon dioxide emissions by 5% from 1990 levels in the Kyoto protocol—without being able to know whether those targets are efficient. However, we can still evaluate whether a policy will be cost effective and achieve its goal in the least expensive way possible. For example, for total pollution reduction to be distributed cost-effectively between all the sources that contribute pollution to an area (e.g. a lake or an urban airshed), it must be true that each of the sources is cleaning up such that they all face the same marginal costs of further abatement. If one source had a high marginal cost and another's marginal cost was very low, total cost could be reduced by switching some of the cleanup from the first source to the second.

*Incentives to Innovate*

At any one point in time, the cost of pollution control or resource recovery depends on the current state of technology and knowledge. For example, the cost of reducing carbon dioxide emissions from fossil fuels depends in part on how expensive solar and wind power are, and the cost of wetland restoration depends on how quickly ecologists are able to get new wetland plants to be established. Everyone in society benefits if those technologies improve and the marginal cost of any given level of environmental stewardship declines. Thus, economists think a lot about which kinds of policies do the best job of giving people incentives to develop cheaper ways to clean and steward the environment.

*Fairness*

A project can have very high aggregate net benefits, but distribute the costs and benefits very unevenly within society. We may have both ethical and practical reasons not to want a policy that is highly unfair. Some people have strong moral or philosophical preferences for policies that are equitable. In addition, if the costs of a policy are borne disproportionately by a single group of people or firms, that group is likely to fight against it in the political process. Simple cost-benefit analyses do not speak to issues of equity. However, it is common for policy analyses to break total costs and benefits down among subgroups to see if uneven patterns exist in their distribution. Studies can break down policy effects by income category to see if a policy helps or hurts people disproportionately depending on whether they are wealthy or poor. Other analyses carry out regional analyses of policy effects. For example, climate-change mitigation policy increases costs disproportionately for poor households because of patterns in energy consumption across income groups. Furthermore, the benefits and costs of such policy are not uniform across space in the U.S. The benefits of reducing the severity of climate change will accrue largely to those areas that would be hurt most by global warming (coastal states hit by sea level rise and more hurricanes, Western states hit by severe water shortages) while the costs will fall most heavily on regions of the country with economies dependent on sales of oil and coal.

Some of our evaluative criteria are closely related to each other; a policy cannot be efficient if it is not cost-effective. However, other criteria have nothing to do with each other; a policy can be efficient but not equitable, and vice versa. Cost-benefit analyses provide crude litmus tests—we surely do not want to adopt policies that have costs exceeding their benefits. However, good policy development and evaluation considers a broader array of criteria.

## Gross National Product and Its Alternatives

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 contamination (such as hazardous waste sites) help to create new jobs and increase the consumption of natural resources. Alternative systems to GDP have been suggested that are based on genuine wellbeing and progress. The UN Human Development Index is an estimate of the quality of life in a country based on three indicators: life expectancy, literacy rate and per capita GNP. The Genuine Progress Index (GPI) is based on measurements that include health care, safety, clean environment, pollution and crime. The Environmental Performance Index (EPI) is based on indicators tracked in two categories: protection of human health from environmental harm and protection of ecosystems.

## 16.2 Environmental Laws and Regulations

Although environmental laws are generally considered a 20th century phenomenon, attempts have been made to legislate environmental controls throughout history (University of California College Prep, 2012). 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.

### Federal Laws

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

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

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

- •The Federal Clean Air Act (1970, 1977 1990) established national standards for regulating the emission of pollutants from stationary and mobile sources.
- •The Federal Water Pollution Control Act (1972) amended by the Clean Water Act (1977, 1987), established water quality standards; provides for the regulation of the discharge of pollutants into navigable waters and for the protection of wetlands.
- •The Federal Safe Drinking Water Act (1974, 1977 1986) set drinking water standards for levels of pollutants; authorizing the regulation of the discharge of pollutants into underground drinking water sources.
- •The Toxic Substances Control Act (1976) provided for the regulation of chemical substances by the EPA and the safety testing of new chemicals.
- •The Resource Conservation and Recovery Act (1976) established cradle-to-grave regulations for the handling of hazardous wastes.
- •The Comprehensive Environmental Response, Compensation and Liability Act (1980), also known as the Superfund program, provided for the cleanup of the worst toxic waste sites.
- •The Food Security Act (1985, 1990) later amended by the Federal Agriculture Improvement and Reform Act (1996), discouraged cultivation of environmentally sensitive lands, especially wetlands, and authorized incentives for farmers to withdraw highly erodible lands from production.

The application, or enforcement, of an environmental law is not always straightforward, and problems can arise. Often, the biggest problem is that Congress fails to allocate the funds necessary for implementing or enforcing the laws. Administrative red tape may make it impossible to enforce a regulation 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.

### State Laws

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

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

### International Treaties and Conventions

Conventions, or treaties, generally set forth international environmental regulations. These conventions and treaties often result from efforts by international organizations such as the United Nations (UN) or the World Bank. However, it is often difficult, if not impossible, to enforce these regulations because of the sovereign rights of countries. In addition rules and regulations set forth in such agreements may be no more than non-binding recommendations, and often countries are exempted from regulations due to economic or cultural reasons. Despite these shortcomings, the international community has achieved some success via its environmental agreements. These include an international convention that placed a moratorium on whaling (1986) and a treaty that banned the ocean dumping of wastes (1991).

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

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

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

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

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

## 16.3 Resources

### Summary

Environmental and natural resource economists study the tradeoffs associated with one of the most important scarce resources we have—nature. 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 costs are considered relevant. External costs are harmful social or environmental effects caused by the production or consumption of economic goods. A cost-benefit analysis provides an estimate of the most economically efficient level of pollution reduction that is practical. 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. 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).

### Review Questions

1. How do externalities cause market outcomes not to be efficient?
2. How are the free rider problem and the common pool resource problem related to basic problems of externalities?
3. What is discounting, and how do we use it in calculating the costs and the benefits of a project that has effects over a long period of time?
4. Why is discounting controversial?
5. How does cost-benefit analysis complement some of the other measures people use to evaluate a policy or project?
6. List major international environmental laws of the past two decades.

## 16.4 References

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# CHAPTER 17 Sustainability and Urban Infrastructure

## Chapter Outline



FIGURE 17.1

Walkability is a key component of any sustainable neighborhood. Walkability not only reduces energy use, but also increases public health. Picture shows a pedestrian street in Ljubljana, Slovenia. Gajšek, V. (2011). VidGajsek - Copova bottomup. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:VidGajsek_-_Copova_bottomup.jpg

### Learning Outcomes

After studying this chapter, you should be able to:

- Define urbanization
- Recognize some of the main urbanization challenges facing the developing world
- Describe impacts from urban sprawl
- Explain green urbanism

# 17.1 Urbanization and Cities

**Urbanization** is the study of the social, political, and economic relationships in cities, and someone specializing in **urban sociology** would study those relationships (William, 2012). In some ways, cities can be microcosms of universal human behavior, while in others they provide a unique environment that yields their own brand of human behavior. There is no strict dividing line between rural and urban; rather, there is a continuum where one bleeds into the other. However, once a geographically concentrated population has reached approximately 100,000 people, it typically behaves like a city regardless of what its designation might be.

There are three prerequisites for the development of a city. First, **good environment** with fresh water and a favorable climate; second, **advanced technology**, which will produce a food surplus to support non-farmers; and third, **strong social organization** to ensure social stability and a stable economy. Most scholars agree that the first cities were developed somewhere in ancient Mesopotamia, though there are disagreements about exactly where. Most early cities were small by today's standards, and the largest city around 100 CE was most likely Rome, with about 650,000 inhabitants. The factors limiting the size of ancient cities included lack of adequate sewage control, limited food supply, and immigration restrictions. For example, serfs were tied to the land, and transportation was limited and inefficient. Today, the primary influence on cities' growth is economic forces.

## Growth of Urban Populations

Urbanization levels are affected by two things – migration and natural increase (Coolgeography, n.d.). **Migration** is the movement of population from one area to another. Some migrations are forced, voluntary, permanent and temporary, international and regional. Rural to urban migration, is the movement of people from countryside to city areas. This type of migration happened in developed countries from the *18th century onwards* on a large scale, and has gradually slowed down. However, many developing countries are experiencing massive rural to urban migration, mainly of young males, into the major cities.

The major reasons for migration can be classified into push and pull factors. A **push factor** is something that can force or encourage people to move away from a country. Push factors can include famine (as in Ethiopia in the 1980s), drought, flooding, a lack of employment opportunities, population growth, over population, and civil war. A **pull factor** is one in which encourages people to move to a city. Pull factors include the chance of a better job, better access to education and services, a higher standard of living. These factors have contributed to millions of people in developing countries moving to cities, creating mass urbanization. **Natural increase** (a population increase due to more births and fewer deaths) also has a major effect on rates of urbanization. Natural increase is stimulated by better access to medical care, improved water supplies, sanitary conditions and wealth.

## Suburbs and Exurbs

As cities grew and became more crowded (and often more impoverished and costly) more and more people began to migrate back out of them. But instead of returning to rural small towns (like they had resided in before moving to the city), these people needed close access to the cities for their jobs. In the 1850s, as the urban population greatly expanded and transportation options improved, suburbs developed. **Suburbs** are the communities surrounding cities, typically close enough for a daily commute in, but far enough away to allow for more space than city living affords. The bucolic suburban landscape of the early 20th century has largely disappeared due to sprawl.

**Urban sprawl** contributes to *traffic congestion*, which in turn contributes to commuting time. Commuting times and distances have continued to increase as new suburbs developed farther and farther from city centers. Simultaneously, this dynamic contributed to an exponential increase in natural resource use, like petroleum, which sequentially increased *pollution* in the form of carbon emissions (negative aspects of urban sprawl will be explored further in the following section).

As the suburbs became more crowded and lost their charm, those who could afford it turned to the **exurbs**, communities that exist outside the ring of suburbs and are typically populated by even wealthier families who want more space and have the resources to lengthen their commute. It is interesting to note that unlike U.S. cities, Canadian cities have always retained a fairly large elite residential presence in enclaves around the city centers, a pattern that has been augmented in recent decades by patterns of inner-city resettlement by elites. As cities evolve from industrial to postindustrial, this practice of **gentrification** becomes more common. Gentrification refers to members of the middle and upper classes entering city areas that have been historically less affluent and renovating properties while the poor urban underclass are forced by resulting price pressures to leave those neighborhoods. This practice is widespread and the lower class is pushed into increasingly decaying portions of the city.

Together, the city centers, suburbs, exurbs, and metropolitan areas all combine to form a **metropolis**. New York was the first North American **megalopolis**, a huge urban corridor encompassing multiple cities and their surrounding suburbs. The Toronto-Hamilton-Oshawa and Calgary-Edmonton corridors are similar megalopolis formations. These metropolises use vast quantities of natural resources and are a growing part of the North American landscape.

## 17.2 Urbanization Around the World

As was the case in North America, other urban centers experienced a growth spurt during the Industrial Era (William, 2012). In 1800, the only city in the world with a population over 1 million was Beijing, but by 1900, there were 16 cities with a population over 1 million. The development of factories brought people from rural to urban areas, and new technology increased the efficiency of transportation, food production, and food preservation. For example, from the mid-1670s to the early 1900s, London increased its population from 550,000 to 7 million.

The growth in global urbanization in the 20th and 21st centuries is following the blueprint of North American cities, but is occurring much more quickly and at larger scales, especially in peripheral and semi-peripheral countries. Shanghai almost tripled its population from 7.8 million to 20.2 million between 1990 and 2011, adding the equivalent of the population of New York City in 20 years. It is projected to reach 28.4 million by 2025, third in size behind Tokyo (38.7 million) and New Delhi (32.9 million).

### Urban Environmental Problems of the Developing World

Global urbanization reached the 50 percent mark in 2008, meaning that more than half of the global population was living in cities compared to only 30 percent 50 years ago. The access to basic services— clean water, sanitation, electricity, and roads—are some of the main urbanization challenges facing the developing world.

Municipal **waste** management is a crucial service provided by cities around the world, but is often inefficient and underperforming in developing countries. Low income countries face the most acute challenges with solid waste management (World Bank, 2014). In low income countries, cities collect less than half the waste stream. Of this, only about half is processed to minimum acceptable standards. Improper waste management, especially open dumping and open burning, has significant adverse effects on water bodies, air and land resources. People who live near or work with solid waste have increased disease burdens. Unmanaged waste also frequently blocks drainage systems and worsens flooding. Even when collected and transported, waste in dumpsites and landfills contributes to greenhouse gas emissions.

Roughly 2.6 billion people in the developing world are without adequate **sanitation**, and facilities are often overloaded, in disrepair, or unused. Even though the sanitation gap is twice as large as that of water supply, investments in sanitation and hygiene have lagged far behind those in water and other "social" sectors, such as health and education. The main costs of urban sanitation services are those of sewers and sewage treatment. Whereas sewers contribute to public health through reducing everyday contact with sewage (especially by children), wastewater treatment is designed largely to meet ecological objectives and not those of public health. Urban utilities, by and large, are not well designed or staffed to address off-network solutions for water supply or sanitation, yet those solutions are likely to be the most important first steps of progress in environmental health for many of the urban poor.

Experience suggests that demand for car ownership increases dramatically at annual household incomes of $6,000–$8,000. If history repeats itself, an additional 2.3 billion cars will be added by 2050, mostly in developing countries, given expected economic growth and past patterns of motorization (World Bank, 2013). For instance, in the six largest cities in India, the population doubled between 1981 and 2001, but the number of motor vehicles increased eight times over the same period. Between 2000 and 2013, car ownership in China increased more than six times. Similar trends are seen in other fast growing economies. Increased income levels and the availability of cheaper personal vehicles, coupled with increased travel distances and inadequate public transport systems, have made the personal motorcar an increasingly attractive travel option. The associated health costs are high—in Beijing, the health costs from local **air pollution** are estimated at $3.5 billion annually. In Pakistan, more than 22,600 adult deaths were attributable to urban ambient air pollution in 2005 where air pollution alone causes more than 80,000 hospital admissions per year, nearly 8,000 cases of chronic bronchitis, and almost 5 million cases of lower respiratory cases among children under five (Sanchez-Triana, Enriquez, Afzal, Nakagawa, & Khan, 2014).

**Slum cities** refer to the development on the outskirts of cities of unplanned shantytowns or squats with no access to clean water, sanitation, or other municipal services. These slums exist largely outside the rule of law and have become centers for child labor, prostitution, criminal activities, and struggles between gangs and paramilitary forces for control. Mike Davis (2006) estimates that there are 200,000 slum cities worldwide including Quarantina in Beirut, the Favéla in Rio de Janeiro, the "City of the Dead" in Cairo, and Santa Cruz Meyehualco in Mexico City. He notes that while slum residents constitute only 6 percent of the urban population in developed countries, they constitute 78.2 percent of city dwellers in semi-peripheral countries. In Davis's analysis, neoliberal restructuring and the Structural Adjustment Programs of the World Bank and the International Monetary Fund (IMF) are largely responsible for the creation of the informal economy and the withdrawal of the state from urban planning and the provision of services. As a result, slum cities have become the blueprint for urban development in the developing world.

# 17.3 The Impacts of Urban Sprawl

Urban sprawl is the extension of low-density residential, commercial, and industrial development into areas beyond a city's boundaries that occurs in an unplanned or uncoordinated manner (EEA, 2006). It is generally characterized by:

- low-density development that is dispersed and situated on large lots (greater than one acre)
- geographic separation of essential places such as work, home, school, and shopping
- high dependence on automobiles for travel
- increased impervious surface area in watersheds
- habitat fragmentation and degradation

Urban sprawl combines low density (see Figure 17.4) and fragmentation of the urban area (see Figure 17.2), increases the average travel distances for daily trips, and hinders a shift toward less energy-intensive transportation modes.

The sprawling nature of cities is critically important because of the major impacts that are evident in increased energy, land and soil consumption. These impacts threaten both the natural and rural environments, raising greenhouse gas emissions that cause climate change, and elevated air and noise pollution levels which often exceed the agreed human safety limits. Thus, urban sprawl produces many adverse impacts that have direct effects on the quality of life.

## Health

If communities are not walkable or bikeable, we need to drive to schools, shops, parks, entertainment, play dates, etc. Thus we become more sedentary. Residents of sprawling counties were likely to walk less during leisure time and weigh more than residents of compact counties. A sedentary lifestyle increases the risk of overall mortality, cardiovascular disease, and some types of cancer. The effect of low physical fitness is comparable to that of hypertension, high cholesterol and diabetes.

## Consumption of Energy

A consequence of the increasing consumption of land and reductions in population densities as cities sprawl is the growing consumption of energy. Generally, compact urban developments with higher population densities are more energy efficient. Evidence from 17 cities around the world shows a consistent link between population density and energy consumption (Figure 17.3), and in particular high energy consumption rates that are associated with lower population densities, characteristic of sprawling environments, dependent on lengthy distribution systems that undermine efficient energy use.

Transport related energy consumption in cities depends on a variety of factors including the nature of the rail and road networks, the extent of the development of mass transportation systems, and the modal split between public and private transport. Evidence shows that there is a significant increase in travel related energy consumption in cities as densities fall. Essentially, the sprawling city is dominated by relatively energy inefficient car use, as the car is frequently the only practical alternative to more energy efficient, but typically inadequate, relatively and increasingly expensive public transportation systems. Increased transport related energy consumption is in turn leading to an increase in the emission of $CO_2$ to the atmosphere. Urban sprawl therefore poses significant threats to the commitments to reduce GHG gas emissions.

| | Sprawling City | Compact City |
|---|---|---|
| |  |  |
| Location | Atlanta | Barcelona |
| Urban Population (million inhabitants) | 2.5 | 2.8 |
| Urban Area ($km^2$) | 4,280 | 162 |
| Urban Density (pph) | 6 | 173 |
| Energy Consumption Per Capita for Private Transportation (MJoules) | 80 | 9 |

FIGURE 17.2

Sprawl vs. Compact Cities. An often cited example of urban sprawl is Atlanta, GA (US), which has a similar population as Barcelona but occupies an urban area that is 26 times as large

### Air pollution

Using fossil fuels also results in the emission of other gases and particulates that degrade air quality (note that commuters generate emissions of air pollution, which lowers the ambient quality of the air in areas they pass through and causes health problems for other people). Longer transportation distances intensify traffic congestion, resulting in lost productivity, and increase the need for more extensive infrastructure (such as more highways) that negatively impact the environment by increasing the amount of impervious cover and by requiring more natural resources. Finally, traffic congestion and air pollution from driving contribute to an estimated 900,000 fatalities per year worldwide.

### Natural and Protected areas

The impacts of sprawl on natural areas are significant. The considerable impact of urban sprawl on natural and protected areas is exacerbated by the increased proximity and accessibility of urban activities to natural areas, imposing stress on ecosystems and species through noise and air pollution. Immediate impacts such as the loss

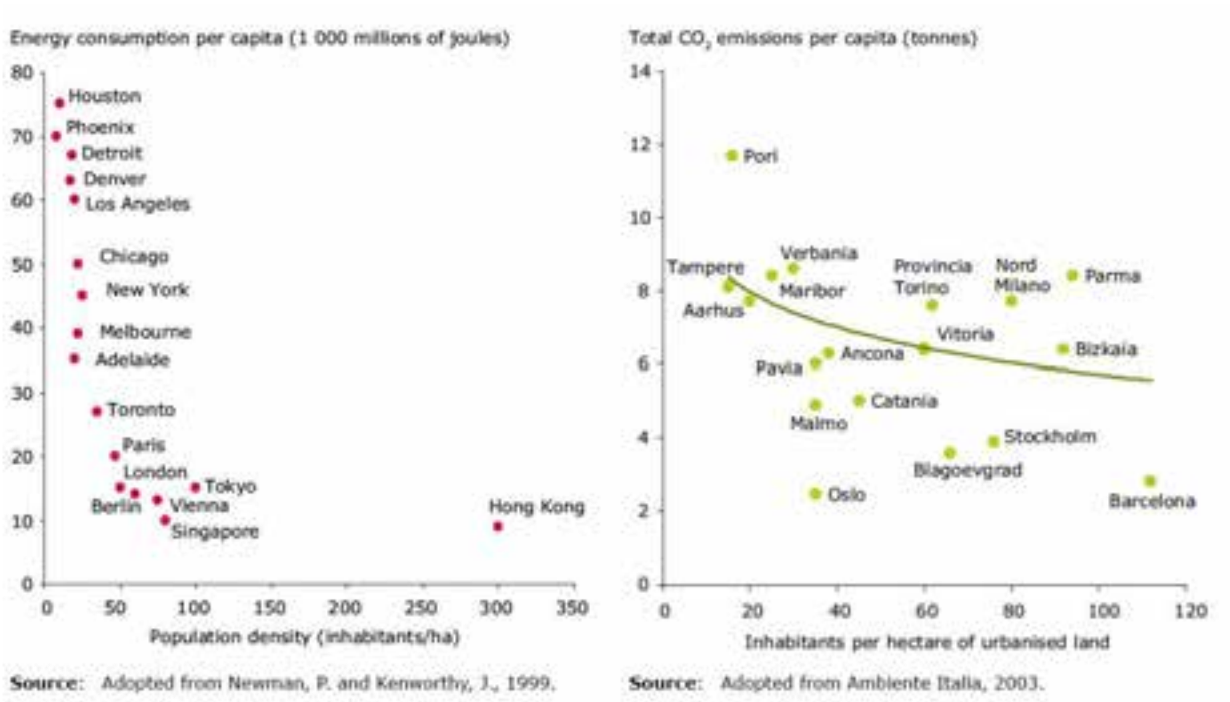



FIGURE 17.3

Left: Population density and energy consumption, selected World cities. Right: Population density and CO2 emissions, selected European cities.

FIGURE 17.4

Sprawling area.

Dhaluza. (2007). Bellefonte Pennsylvania. (JPG). Retrieved from https://commons.wikimedia.org/wiki/Category:Aerial_photographs_of_Pennsylvania#/media/File:Bellefonte_Pennsylvania.jpg of agricultural and natural land or the fragmentation of forests (Figure 17.5), wetlands and other habitats are well known direct and irreversible impacts. Urban land fragmentation, with the disruption of migration corridors for wildlife species, isolates these populations and can reduce natural habitats to such an extent that the minimum area required for the viability of species populations is no longer maintained.

FIGURE 17.5
Forrest fragmentation.

The environmental impacts of sprawl are evident in a number of ecologically sensitive areas located in coastal zones and mountain areas. The Mediterranean coast, one of the world's 34 biodiversity hotspots, is particularly affected, and the increased demand for water for urban use, competes with irrigation water for agricultural land. This problem has been exacerbated by the increased development of golf courses in Spain, where the over-extraction of groundwater has led to salt water intrusion into the groundwater. Increased transit and tourist traffic, particularly day tourism from the big cities, also adds to the exploitation of the mountain areas as a natural resource for 'urban consumption' by the lowland populations.

### Rural Environments

The growth of European cities in recent years has primarily occurred on former agricultural land. Typically, urban development and agriculture are competing for the same land, as agricultural lands adjacent to existing urban areas are also ideal for urban expansion. The loss of agricultural land has major impacts on biodiversity with the loss of valuable biotopes for many animals, and particularly birds. Sprawling cities also threaten to consume the best agricultural lands, displacing agricultural activity to both less productive areas (requiring higher inputs of water and fertilizers) and more remote upland locations (with increased risk of soil erosion).

### Soil

Urban sprawl and the development of urban land dramatically transform the properties of soil, reducing its capacity to perform its essential functions. These impacts are evident in the extent of compaction of soil leading to impairment of soil functions; loss of water permeability (soil sealing) which dramatically decreases; loss of soil biodiversity, and reductions of the capacity for the soil to act as a carbon sink. In Germany, for example, it is estimated that 52 % of the soil in built-up areas is sealed (or the equivalent of 15 m2 per second over a decade). In addition, rainwater which falls on sealed areas is heavily polluted by tire abrasion, dust and high concentrations of heavy metals, which when washed into rivers degrade the hydrological system.

### Water Quality

Increasing numbers of roads and parking lots are needed to support an automobile transportation system, which lead to increased non-point source water pollution and contamination of water supplies (road runoff of oil/gas, metals, nutrients, organic waste, to name a few) with possible impacts on human health. Increased erosion and stream siltation causes environmental damage and may affect water treatment plants and thus affect water quality.

### Socio-economic Impacts

From a social perspective urban sprawl generates greater segregation of residential development according to income. Consequently, it can exacerbate urban social and economic divisions. The socio[U+2011]economic character of suburban and peripheral areas is typified by middle and upper income families with children, who have the necessary mobility and lifestyle to enable them to function effectively in these localities. However, the suburban experience for other groups, including the young and old, who lack mobility and resources can be very different and can reduce social interaction. Furthermore, large segments of urban society are excluded from living in such areas.

From an economic perspective urban sprawl is at the very least a more costly form of urban development due to:

- increased household spending on commuting from home to work over longer and longer distances;
- the cost to business of the congestion in sprawled urban areas with inefficient transportation systems;
- the additional costs of the extension of urban infrastructures including utilities and related services, across the urban region.

Urban sprawl inhibits the development of public transport and solutions based on the development of mass transportation systems, and the provision of alternative choices in transportation that are essential to ensure the efficient working of urban environments. These conclusions are reinforced by experience from both Munich and Stockholm where the efficient control of urban sprawl and resulting increase in population densities fosters the use of public transport and reduces the growth of car use.

### Social Capital

On the social sustainability side, we can look at social capital otherwise defined as the "connectedness" of a group built through behaviors such as *social networking* and *civic engagement*, along with attitudes such as trust and reciprocity. Greater social capital has been associated with healthier behaviors, better self-rated health, and less negative results such as heart disease. However, social capital has been diminishing over time. Proposed causes include long commute times, observed in sprawling metropolitan areas. As of 2011, according to an article in the Chicago Tribune, Chicago commuting times are some of the worst – with Chicagoans spending 70 hours per year more on the road than they would if there was no congestion – up from 18 hours in 1982. They have an average commute time of 34 minutes each way. These drivers also use 52 more gallons per year per commuter.

# 17.4 The Sustainable City

Sustainability, from science to philosophy to lifestyle, finds expression in the way we shape our cities (Theis & Tomkin, 2015). Cities are not just a collection of structures, but rather groups of people living different lifestyles together. When we ask if a lifestyle is sustainable, we're asking if it can endure. Some archaeologists posit that environmental imbalance doomed many failed ancient civilizations. What could the sustainable city look like, how would it function, and how can we avoid an imbalance that will lead to the collapse of our material civilization? This module will make some educated guesses based upon the ideas and practices of some of today's bold innovators.

Throughout history settlement patterns have been set by technology and commerce. Civilizations have produced food, clothing and shelter, and accessed foreign markets to purchase and sell goods. Workers traditionally had to live near their place of occupation, although in modern industrial times advanced transportation systems have enabled us to live quite a distance from where we work.

In hindsight we can see how reliance on water and horse-drawn transportation shaped historical civilizations and how this equation was radically altered with the rise of the automobile following World War II. While attempting to envision the "Sustainable City" we must discern what factors will influence its shape and form in the future.

## Green Urbanism and Sustainable Cities

Green urbanism is a conceptual model that seeks to transform and re-engineer existing city districts and regenerate the post-industrial city center. It promotes the development of socially and environmentally sustainable city districts. The following principles of green urbanism offer practical steps on the path to sustainable cities, harmonizing growth and usage of resources.

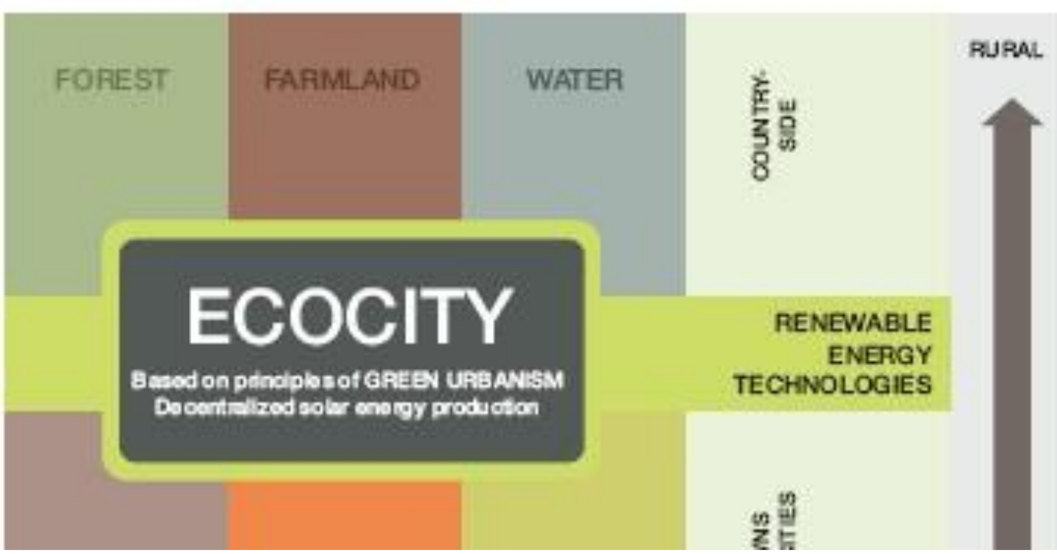
### Climate and Context

Every site or place has its own unique individual conditions in regard to orientation, solar radiation, rain, humidity, prevailing wind direction, topography, shading, lighting, noise, air pollution and so on (Lehmann, 2010). The various aspects of this principle include: Climatic conditions, which are seen as the fundamental influence for form-generation in the design of any project; understanding the site and its context, which is essential at the beginning of every sustainable design project; optimizing orientation and compactness to help reduce the city district's heat gain or losses; achieving a city with minimized environmental footprint by working with the existing landscape, topography and resources particular to the site, and the existing micro-climate of the immediate surroundings. Maintaining complexity in the system is always desirable (be it biodiversity, eco-system or neighborhood layout), and a high degree of complexity is always beneficial for society. Enhancing the opportunities offered by topography and natural setting leads to a city well adapted to the local climate and its eco-system. We can use the buildings' envelope to filter temperature, humidity, light, wind and noise. Due to the different characteristics of every location, each city district has to come up with its own methods and tailored strategies to reach sustainability and to capture the spirit of the place. Each site or city is different and the drivers for re-engineering existing districts will need to understand how to take full advantage of each location's potential, and how to fine-tune the design concept to take advantage of local circumstances. As an aim, all urban development must be in harmony with the specific characteristics, various site factors and advantages of each location and be appropriate to its societal setting and contexts (cultural, historical, social, geographical, economical, environmental and political). In future, all buildings should have climate-adapted envelope technologies, with facades that are fully climate-responsive.

### Renewable Energy for Zero $CO_2$ Emissions

The various aspects of this principle include: Energy supply systems and services, as well as energy efficient use and operation, promoting increased use of renewable power, and perhaps natural gas as a transition fuel in the


GREEN URBANISM
• Embodied energy
• Material specification
• Supply chain
• Renewable energy solutions
• Energy sources and consumption
• Construction systems
• Prefabrication and recycling
• Energy efficiency
• Resource management
ENERGY and MATERIALS
• Urban water management
• Water recycling and irrigation
• Urban Farming
• Urban landscape typologies
• Ecosystems' biodiversity maximized
• Grey water recycling
• Storage of urban stormwater
• Climate change impact management
• Waste management
WATER and BIODIVERSITY
• Urban design
• Social sustainability
• Ecological city theory
• Health and walkability
• Mobility, public Transport
• Infrastructure
• Energy efficient buildings
• Mixed land use
• Housing affordability
• Reducing car dependency
• Subdivisions
URBAN PLANNING and TRANSPORT
Interaction between three main pillars


FOREST
FARMLAND
WATER
COUNTRY-SIDE
RURAL
ECOCITY
Based on principles of GREEN URBANISM
Decentralized solar energy production
RENEWABLE ENERGY TECHNOLOGIES

energy mix, but always moving quickly away from heavy fossil-fuels such as coal and oil; and the transformation of the city district from an energy consumer to an energy producer, with local solutions for renewables and the increasing de-carbonizing of the energy supply. The supply of oil will last shorter than the life-expectancy of most buildings. The local availability of a renewable source of energy is the first selection criteria for deciding on energy generation. In general, a well-balanced combination of energy sources can sensibly secure future supply. A necessary aim is also to have a distributed energy supply through a decentralized system, utilizing local renewable energy sources. This will transform city districts into local power stations of renewable energy sources, which will include solar PV, solar thermal, wind (on- and off-shore), biomass, geothermal power, mini-hydro energy and other new technologies. Some of the most promising technologies are in building-integrated PV, urban wind turbines, micro CHP and solar cooling. That is to say, there should be on-site electrical generation and energy storage in combination with a smart grid, which integrates local solar and wind generation, utilizing energy-efficiency in all its forms. Solar hot water systems would be compulsory. Co-generation technology utilizes waste heat through CHP combined-heat-and-power plants. Energy-efficiency programs are not enough. Too often we find that savings from energy-efficiency programs are absorbed by a rise in energy use. Genuine action on climate change means that coal-fired power stations cease to operate and are replaced by renewable energy sources. Eco-districts will need to operate on renewable energy sources as close to 100 per cent as possible. As a minimum, at least 50 per cent of on-site renewable energy generation should be the aim of all urban planning, where the energy mix comes from decentralized energy generation and takes into account the resources that are locally available, as well as the cost and the availability of the technology. Optimizing the energy balance can be achieved by using exchange, storage and cascading (exergy) principles. It is, therefore, essential that the fossil-fuel powered energy and transportation systems currently supporting our cities are rapidly turned into systems that are supplied by renewable energy sources. High building insulation, high energy-efficiency standards and the use of smart metering technology is essential, so that if a part of an office building is not in use, the intelligent building management system will shut down lights and ventilation.

### Zero-Waste

Sustainable waste management means to turn waste into a resource. All cities should adopt nature's zero-waste management system (See Box below). Zero-waste urban planning includes reducing, recycling, reusing and composting waste to produce energy. All material flows need to be examined and fully understood, and special attention needs to be given to industrial waste and e-waste treatment. We need to plan for recycling centers, for zero landfill and 'eliminating the concept of waste' and better understanding nutrient flows. Eco-districts are neighborhoods where we reuse and recycle materials and significantly reduce the volume of solid waste and toxic chemical releases. All construction materials as well as the production of goods (and building components) need to be healthy and fully- recyclable.

Waste prevention is always better than the treatment or cleaning-up after waste is formed. Some other systems that need to be put in place are: the remanufacturing of metals, glass, plastics, paper into new products needs to be a routine (without down-grading the product); waste-to-energy strategies are needed for residual waste; and an 'extended producer responsibility' clause is needed for all products. In this context of waste, better management of the nitrogen cycle has emerged as an important topic: to restore the balance to the nitrogen cycle by developing improved fertilization technologies, and technologies in capturing and recycling waste. Controlling the impact of agriculture on the global cycle of nitrogen is a growing challenge for sustainable development. Essentially, we need to become (again) a *recycling society*, where it is common that around 60 to 90 per cent of all waste is recycled and composted.

### Water

The various aspects of this principle include, in general, reducing water consumption, finding more efficient uses for water resources, ensuring good water quality and the protection of aquatic habitats. The city can be used as a water catchment area by educating the population in water efficiency, promoting rainwater collection (see Figure below) and using wastewater recycling and storm water harvesting techniques. Storm water and flood management concepts need to be adopted as part of the urban design, and this includes storm water run-offs and improved drainage systems and the treatment of wastewater.


FIGURE 17.7

Description of Rainwater Harvesting Techniques (1) and a Sample Dual-Flush Water-Efficient Toilet (2) at a Rio de Janeiro Hardware Store.

As part of the eco-district's adequate and affordable health care provisions, it needs to ensure the supply of safe water and sanitation. This includes such things as algae and bio-filtration systems for grey water and improving the quality of our rivers and lakes so that they are fishable and swimmable again. An integrated urban water cycle planning and management system that includes a high-performance infrastructure for sewage recycling (grey and black water recycling), storm water retention and harvesting the substantial run-off through storage, must be a routine in all design projects. On a household level we need to collect rain water and use it sparingly for washing and install dual-water systems and low-flush toilets. On a food production level we need to investigate the development of crops that need less water and are more drought resistant.

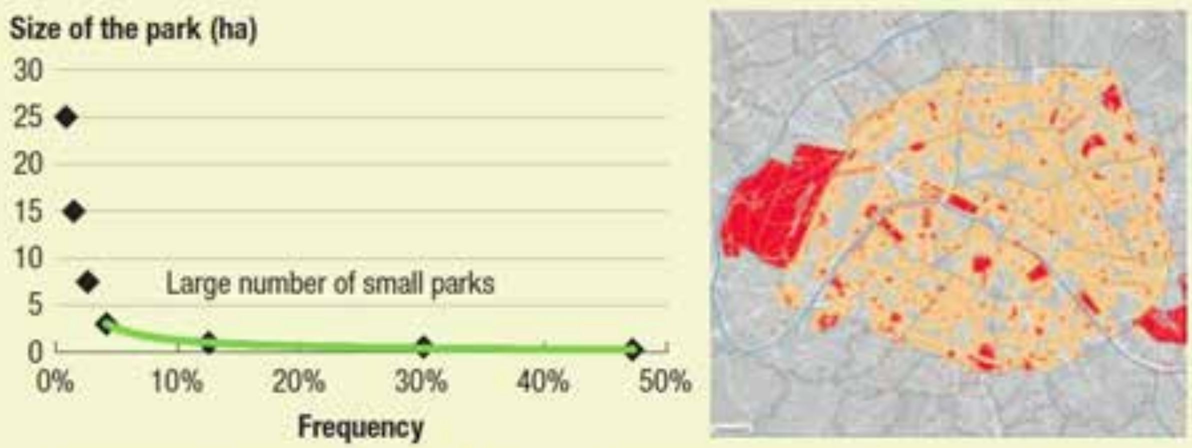
**Landscape, Gardens and Urban Biodiversity**

A sustainable city takes pride in its many beautiful parks and public gardens. This pride is best formed through a strong focus on local biodiversity, habitat and ecology, wildlife rehabilitation, forest conservation and the protecting of regional characteristics. Ready access to these green spaces (See figure 17.9): public parks, gardens, with opportunities for leisure and recreation, are essential components of a healthy city. As is arresting the loss of biodiversity by enhancing the natural environment and landscape, and planning the city using ecological principles based on natural cycles (not on energy-intensive technology) as a guide, and increasing urban vegetation. A city that preserves and maximizes its open spaces, natural landscapes and recreational opportunities is a more healthy and resilient city. The sustainable city also needs to introduce inner-city gardens, **urban farming** and **green roofs** in all its urban design projects (using the city for food supply).

FIGURE 17.8

Urban Farming in Chicago. Some new crops being started, protected by shade cloth barriers to the west.
Linda. (2008). New crops-Chicago urban farm. (JPG)> Retrieved from https://commons.wikimedia.org/wiki/File%3ANew_crops-Chicago_urban_farm.jpg.

It needs to maximize the resilience of the eco-system through urban landscapes that mitigate the 'urban heat island' (UHI) effect, using plants for air-purification and urban cooling. Further, the narrowing of roads, which calms traffic and lowers the UHI effect, allows for more (all-important) tree planting. Preserving green space, gardens and farmland, maintaining a green belt around the city, and planting trees everywhere (including golf courses), as trees absorb $CO_2$, is an important mission.




Left: Long tail distribution of parks in Paris, with the long tail of small parks in green.
Right: Numerous small parks in Paris ensure 5 minute walk accessibility to parks (red) to 80% of the people.

FIGURE 17.9

Green spaces are an essential feature of energy efficient and livable cities. However, many urban policies concerning green spaces in emerging countries' cities boil down to a predetermined percentage of green space. What really matters is access and proximity of green spaces with diversified social activities instead of proportion only. The spatial distribution of green spaces in Paris results from policies and regulations that have ensured that every citizen lives less than 400 m from a public park, square, or garden. This target has been reached whereas green spaces only represent 5 percent of the urban area. There are a few large parks that allow a wide range of activities for residents, and a large number of very successful pocket parks for daily family activities and intergenerational mix (300 green spaces less than ó ha). As a comparison, green spaces in Beijing represent 30 percent of the urban area. Most of the green spaces are very big parks, and the long tail of small parks is lacking. As a result, residents live more than 3 km away from public parks on average.

Energy Sector Management Assistance Program. (2014). Planning energy efficient and livable cities. World Bank, Washington, DC. © World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/21308 Available under Available under Creative Commons Attribution License 3.0 (CC BY 3.0 IGO). Modified from original.

As is conserving natural resources, respecting natural energy streams and restoring stream and river banks, maximizing species diversity. At home, we need to de-pave the driveway or tear up parking lots. In all urban planning, we need to maintain and protect the existing eco-system that stores carbon (e.g. through a grove or a park), and plan for the creation of new carbon storage sites by increasing the amount of tree planting in all projects. The increase in the percentage of green space as a share of total city land is to be performed in combination with densification activities.

**Sustainable Transport and Good Public space: Compact and Poly-Centric Cities**

Good access to basic transport services is crucial, as it helps to reduce automobile dependency, as does reducing the need to travel. We need to see integrated non-motorized transport, such as cycling or walking, and, consequently, bicycle/pedestrian-friendly environments, with safe bicycle ways, free rental bike schemes and pleasant public spaces. It is important to identify the optimal transport mix that offers inter-connections for public transport and the integration of private and public transport systems.

Some ideas here include: eco-mobility concepts and smart infrastructure (electric vehicles); integrated transport systems (bus transit, light railway, bike stations); improved public space networks and connectivity, and a focus on transport-oriented development. It is a fact that more and wider roads result in more car and truck traffic, and $CO_2$ emissions, and also allows for sprawling development and suburbs that increases electricity-demand and provides less green space. The transport sector is responsible for causing significant greenhouse-gas emissions (over 20 per cent). To combat this effect we need to change our lifestyles by, for example, taking public transport, driving the car less, or car-pooling. Alternatively, we can ride a bike or walk, if the city district has been designed for it. Personal arrangements have the potential to reduce commuting and to boost community spirit. We want a city district which is well-connected for pedestrians, a city with streetscapes that encourage a healthy, active lifestyle and where residents travel less and less by car.

**Density and Retrofitting of Existing Districts**

The various aspects of this principle include: encouraging the densification of the city center through mixed- use urban infill (see Figure 17.10), center regeneration and green transit-oriented development (TOD); increasing sustainability through density and compactness; promoting business opportunities around green transit-oriented developments; optimizing the relationship between urban planning and transport systems; retrofitting inefficient building stock and systematically reducing the city district's carbon footprint.

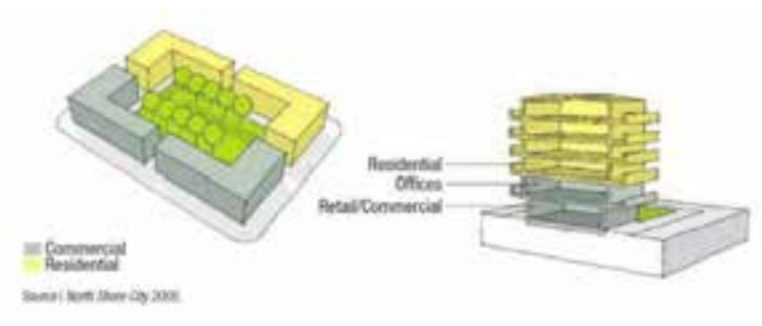



FIGURE 17.10

Mixed Use on the Block and Building Scale.

Energy Sector Management Assistance Program. (2014). Planning energy efficient and livable cities. World Bank, Washington, DC. © World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/21308 Available under Available under Creative Commons Attribution License 3.0 (CC BY 3.0 IGO). Modified from original.

Consideration will need to be given to better land-use planning to reduce the impact of urban areas on agricultural land and landscape; to increasing urban resilience by transforming city districts into more compact communities and designing flexible typologies for inner-city living and working. Special strategies for large metropolitan areas and fast-growing cities are required. Here, examples of rapid development are being provided by Asian cities. Special strategies are also needed for small and medium-sized towns due to their particular milieu, and creative concepts are needed for the particular vulnerabilities of Small Island States and coastal cities. Public space upgrading through **urban renewal** programs will bring people back to the city center. This will need some strategic thinking about how to use brownfield and greyfield developments and also the adaptive reuse of existing buildings. Remodeling and re-energizing existing city centers to bring about diverse and vibrant communities requires people to move back into downtown areas. This can be achieved through mixed-use urban infill projects, building the "city above the city" by converting low density districts into higher density communities; and by revitalizing underutilized land for community benefit and affordable housing.

**Green Buildings and Districts, Using Passive Solar Design Principles.**

The various aspects of this principle include: low-energy, zero-emission designs, applying best practice for **passive solar design principles** (Figure17.11), for all buildings and groups of buildings; dramatically reducing building energy use; introducing compact solar architecture; and renovating and retrofitting the entire building stock. New design typologies need to be developed at low cost, and we need to produce functionally neutral buildings that last longer.

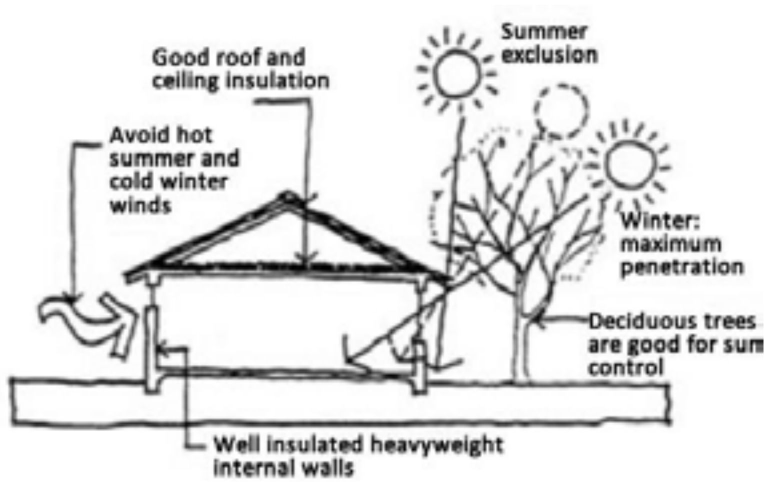



FIGURE 17.11
Passive Solar Design

We need to apply facade technology with responsive building skins for bio-climatic architecture, to take advantage of cooling breezes and natural cross-ventilation, maximizing cross-ventilation, day-lighting and opportunities for night- flush cooling; we need to focus on the low consumption of resources and materials, including the reuse of building elements and design for disassembly. Other ideas include: mixed-use concepts for compact housing typologies; adaptive reuse projects that rejuvenate mature estates; solar architecture that optimizes solar gain in winter and sun shading technology for summer, catching the low winter sun and avoiding too much heat gain in summer. It is important to renew the city with energy-efficient green architecture, creating more flexible buildings of long-term value and longevity. Flexibility in plan leads to a longer life for buildings. Technical systems and services have a shorter life-cycle. This means, first of all, applying technical aids sparingly and making the most of all passive means provided by the building fabric and natural conditions. Buildings that generate more energy than they consume, and collect and purify their own water, are totally achievable. We need to acknowledge that the city as a whole is more important than any individual building.

**Local and Sustainable Materials with Less Embodied Energy**

The various aspects of this principle include: advanced materials technologies, using opportunities for shorter supply chains, where all urban designs focus on local materials and technological know-how, such as regional timber in common use. Affordable housing can be achieved through modular prefabrication. Prefabrication (see Figure 17.1) has come and gone several times in modern architecture, but this time, with closer collaboration with manufacturers of construction systems and building components in the design phase, the focus will be on sustainability. We need to support innovation and be aware of sustainable production and consumption, the embodied energy of materials and the flow of energy in closing life-cycles. We need to emphasize green manufacturing and an economy of means, such as process-integrated technologies that lead to waste reduction. It is more environmentally friendly to use lightweight structures, enclosures and local materials with less embodied energy, requiring minimal transport. We need improved material and system specifications, supported by research in new materials and technological innovation; reduced material diversity in multi-component products to help facilitate the design for resource recovery, disassembly, value retention, and the possibility of reusing entire building components. Success in this area will increase the long-term durability of buildings, reduce waste and minimize packaging.

### TABLE 17.1:

| BOX 1. CASA AQUA |
| --- |
|  |
| In April 2010, a prototype AQUA house for low-income families was exhibited in São Paulo. It measures 40 square meters and has a construction cost of R$45,000 (11,000 USD). Some of the sustainable solutions adopted include a rainwater reuse system, consisting of a cistern and permeable soil; a solar water heater; fiber-cellulose shingles; and soil-cement bricks, which are dimensioned and prefabricated to allow for faster assembly and do not use mortar, thereby reducing costs.<br>A sloped roof with skylights was designed to take advantage of natural light and ventilation. The interior of the house also includes environmentally friendly products such as cement board made from mineralized wood, which does not require finishing, and the use of recycled Tetra Pak packaging on some walls. The house has a dual-flush toilet, which reduces water usage, and fluorescent light bulbs. The construction of the Casa AQUA takes between 30-60 days to complete. (World Bank, 2011). |

**Livability, Healthy Communities and Mixed-Use Programs**

Land use development patterns are the key to sustainability. A mixed-use (and mixed-income) city delivers more social sustainability and social inclusion, and helps to repopulate the city center. Demographic changes, such as age, are a major issue for urban design. It is advantageous for any project to maximize the diversity of its users. Different sectors in the city can take on different roles over a 24 hours cycle; for example, the Central Business District is used for more than just office work. In general we want **connectivity** (see Figure 17.12 ), compact communities, for a livable city, applying mixed-use concepts and strategies for housing affordability, and offering different typologies for different housing needs.

To this end we need affordable and livable housing together with new flexible typologies for inner-city living. These mixed-use neighborhoods (of housing types, prices and ownership forms) have to avoid gentrification and provide affordable housing with districts inclusive for the poor and the rich, young and old, and workers of all walks of life, and also provide secure tenure (ensuring 'aging in place'). Mixed land uses are particularly important as it helps reduce traffic. Master plans should require all private developments to contain 40 to 50 per cent of public (social) housing, and have it integrated with private housing. Higher densities should center on green TODs. Essentially, these changes will aim to introduce more sustainable lifestyle choices, with jobs, retail, housing and a city campus being close by with IT and telecommuting from home significantly helping to reduce the amount of travel.

By integrating a diverse range of economic and cultural activities, we avoid mono-functional projects, which generate a higher demand for mobility. Green businesses would be supported through the use of ethical investments to generate funding.

**Local Food and Short Supply Chains**

The various aspects of this principle include: local food production; regional supply; an emphasis on urban farming and agriculture, including 'eat local' and 'slow food' initiatives. The sustainable city makes provision for adequate land for food production in the city, a return to the community and to the allotment gardens of past days, where roof gardens become an urban market garden. It is essential that we bridge the urban-rural disconnect and move cities towards models that deal in natural eco-systems and healthy food systems.

The people of the eco-city would garden and farm locally, sharing food, creating compost with kitchen scraps and garden clippings and growing ‘community’ vegetables. Buying and consuming locally will be necessary to cut down on petrol-based transport. Such things as re-using bags and glass containers, paper recycling and the cost of food processing will need reconsideration. We will need to reduce our consumption of meat and other animal products,

| | Turi, Estonia | Barcelona, Spain | Paris, France | Ginza, Tokyo | Pudong in Shanghai, China | Towers North in Beijing, China |
|---|---|---|---|---|---|---|
| Intersections per km$^2$ | 152 | 103 | 133 | 211 | 17 | 14 |
| Distance between intersections (m) | 80 | 130 | 150 | 43 | 280 | 400 |

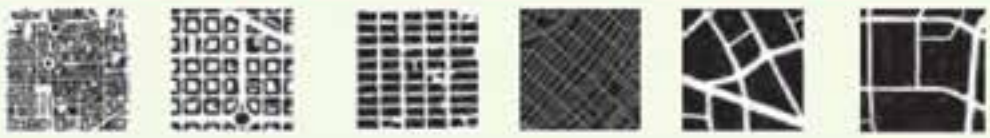


FIGURE 17.12

The Absence of Connectivity and Fine Grain in Chinese Urban Developments. The following pictures illustrate the size of blocks and impacts on connectivity of a series of cities in Europe, Japan, and China. It shows the absence of connectivity and the increase of average distances between intersections in recent urban developments in China.

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FIGURE 17.13

Telecommuting.

Gilangreffi. (2000). Telecommuting di kafe. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File%3ATelecommuting_di_kafe.jpg.

especially shipped-in beef, as the meat cycle is very intensive in terms of energy and water consumption and herds create methane and demand great quantities of electricity. Perhaps as much as 50 per cent of our food will need to be organically produced, without the use of fertilizers or pesticides made from oil, and grown in local allotments.

### Cultural Heritages, Identity and Sense of Place

All sustainable cities aim for air quality, health and pollution reduction, to foster resilient communities, to have strong public space networks and modern community facilities. This is the nature of sustainable cities. However, each city has its own distinct environment, whether it be by the sea, a river, in a dessert, a mountain; whether its climate is tropical, arid, temperate, etc., each situation is unique. The design of the city will take all these factors into consideration, including materials, history and population desires. The essence of place is the up-swelling of grassroots strategies, the protection of its built heritage and the maintenance of a distinct cultural identity, e.g. by promoting locally owned businesses, supporting creativity and cultural development. New ideas require affordable and flexible studio space in historic buildings and warehouses. Cities will grow according to the details and unique qualities of localities, demographic qualities of the populace and the creativity of the authorities and citizens. The aim of a city is to support the health, the activities and the safety of its residents. It is, therefore, incumbent on city councils to protect the city by developing a master plan that balances heritage with conservation and development; fostering distinctive places with a strong sense of place, where densities are high enough to support basic public transit and walk-to retail services.

### Urban Governance, Leadership and Best Practice

Good urban governance is extremely important if we want to transform existing cities into sustainable compact communities. It has to provide efficient public transport, good public space and affordable housing, high standards of urban management, and without political support change will not happen. City councils need strong management and political support for their urban visions to be realized. They need strong support for a strategic direction in order to manage sustainability through coherent combined management and governance approaches, which include evolutionary and adaptive policies linked to a balanced process of review, and to public authorities overcoming their own unsustainable consumption practices and changing their methods of urban decision-making. A city that leads and designs holistically, that implements change harmoniously, and where decision-making and responsibility is shared with the empowered citizenry, is a city that is on the road to sustainable practices. In balancing community needs with development, public consultation exercises and grassroots participation are essential to ensuring people-sensitive urban design and to encouraging community participation. Citizens need to participate in community actions aimed at governments and big corporations, by writing letters and attending city-council hearings. Empowering and enabling people to be actively involved in shaping their community and urban environment is one of the hallmarks of a democracy. Cities are a collective responsibility. As far as bureaucratic urban governance and best practice is concerned, authorities could consider many of the following: updating building code and regulations; creating a database of best practice and worldwide policies for eco-cities; revising contracts for construction projects and integrated public management; raising public awareness; improving planning participation and policy-making; creating sustainable subdivisions, implementing anti-sprawl land-use and growth boundary policies; legislating for controls in density and supporting high-quality densification; arriving at a political decision to adopt the Principles of Green Urbanism, based on an integrated Action Plan; measures to finance a low-to-no-carbon pathway; implementing environmental emergency management; introducing a program of incentives, subsidies and tax exemptions for sustainable projects that foster green jobs; eliminating fossil-fuel subsidies; developing mechanisms for incentives to accelerate renewable energy take-up; implementing integrated land-use planning; having a sustainability assessment and certification of urban development projects.

**Education, Research and Knowledge**

The various aspects of this principle include: technical training and up-skilling, research, exchange of experiences, knowledge dissemination through research publications about ecological city theory and sustainable design. Primary and secondary teaching programs need to be developed for students in such subjects as waste recycling, water efficiency and sustainable behavior. Changes in attitude and personal lifestyles will be necessary. The city is a hub of institutions, such as galleries and libraries and museums, where knowledge can be shared. We must provide sufficient access to educational opportunities and training for the citizenry, thus increasing their chances of finding green jobs. Universities can act as 'think tanks' for the transformation of their cities. We also need to redefine the education of architects, urban designers, planners and landscape architects. Research centers for sustainable urban development policies and best practice in eco-city planning could be founded, where assessment tools to measure environmental performance are developed and local building capacity is studied.

**Strategies for Cities in Developing Countries**

Developing and emerging countries have their own needs and require particular strategies, appropriate technology transfers and funding mechanisms. Cities in the developing world cannot have the same strategies and debates as cities in the developed world. Similarly, particular strategies for emerging economies and fast-growing cities are required, as is the problem of informal settlements and urban slums and slum upgrading programs. Low-cost building and mass housing typologies for rapid urbanization are required in cooperation with poverty reduction programs. It is essential that we train local people to empower communities, creating new jobs and diversifying job structures, so as not to focus on only one segment of the economy (e.g. tourism). Achieving more sustainable growth for Asian metropolitan cities is a necessity. Combating climate change, which was mainly caused through the emissions by industrialized nations and which is having its worst effect in poorer countries in Africa, Asia and Latin America, with a focus on Small Island States, is a priority.

# 17.5 Case Study: Responding to a New Paradigm—The Challenge for Local Authorities

Across the globe, municipalities and their communities are responding to the challenges of making the sustainability Transition (EEA, 1997). Two of these, Chattanooga and Curitiba illustrate the differences in motivation that can impel cities in differing locations and conditions to innovate. Chattanooga was driven to change by the economic, social and health impacts of chokingly high levels of industrial pollution. Within 10 years the city had turned itself around from being the 'most polluted city' in the USA to becoming its 'sustainable development capital'. This story is having a powerful 'demonstration effect' on other cities. But if Chattanooga was a city that was forced to react, Curitiba is an example of a proactive city, an administration that planned for change rather than be overtaken by change. To be sure, neither city is sustainable in the full sense of the word: they both have large ecological footprints, there is still racial division and urban sprawl in Chattanooga, and poor sanitation and squatter settlements in Curitiba. But both cities are unlearning old ways and learning new ways in partnership with their communities and this is the essence of the sustainability challenge.

### Chattanooga, Tennessee: Belle of the Sustainable Cities Ball

FIGURE 17.14

The John Ross Bridge, in Chattanooga, Tennessee.
Gunn, J. (2011). John Ross Bridge, Chattanooga, with barge approaching. (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:John_Ross_Bridge,_Chattanooga,_with_barge_approaching_(2011).jpg.

Fifty years ago the US government labeled Chattanooga, Tennessee, the dirtiest city in America. Today the city is hailed as a sustainability success story by the President's Council on Sustainable Development. Chattanooga's turnaround has inspired communities worldwide and the former manufacturing center is now selling itself as a world leader in the sustainable cities movement. In a matter of decades, the city of 150,000 has transformed its city center into a prime job center and bustling tourist attraction (with a state-of-the-art aquarium); created a revitalized waterfront to which birds are now returning; re-used a former Army facility, once the largest producer of TNT worldwide, as a manufacturing site for electric buses; is attracting clean industry through the development of an Eco industrial park; and is experimenting with 'zero-emission' manufacturing processes. The secret of Chattanooga's success lies in visionary civic leaders, a committed and engaged local population, public private partnerships and adventurous financial investors willing to fund a series of environmental innovations. The process began in 1984 when city residents 'responded to a planning initiative by saying that they wanted more than a strong local economy. They wanted to go fishing without driving out of town, and to be able to eat the fish they caught without worrying about their health'. This led to a visioning process, Vision 2000, which brought together city residents from all walks of life to identify the city's problems — and to find solutions. Forty goals, ranging from providing housing to river cleanup, were set. Pre-existing urban revitalization initiatives fed into, and were transformed by, this process of ecology-based urban renewal. The experimentations continue and the city has adopted sustainable development as its motto — expressed in the shorthand 'equity, environment and economy'. This has become its unique selling point. While Chattanooga's gains are impressive, whether its performance can live up to its marketing claims over time remains to be seen. The city still suffers from chronic urban sprawl and the loss of habitat and agricultural land as do most U.S. cities.

### Curitiba, Brazil: A Laboratory for Sustainable Urban Development

FIGURE 17.15

Historic center of Curitiba.
Anzola, F. (2010). Centro Historico Curitiba (4401512832). (JPG). Retrieved from https://commons.wikimedia.org/wiki/File:Centro_Historico_Curitiba_(4401512832).jpg.

Curitiba is one of the fastest-growing industrial cities in Brazil with a population of over 2.1 million. Yet, compared to other cities its size, Curitiba has significantly less pollution, no gridlocked city center, a slightly lower crime rate and a higher educational level among its citizens. The city is held up as an example of far-sighted and unconventional planning. For example, its 'design with nature strategy' has increased the amount of green space per capita (during a period of rapid population growth), and its mass transit strategy has cut total travel time by a third for its citizens, and contributed to the city having one of the lowest rates of ambient pollution in the country. Curitiba's success lies in the gradual institutionalization (over a period of 30 years) of urban development policies explicitly favoring: public transport over private automobiles; appropriate rather than high-tech solutions; innovation with citizen participation instead of master planning; incentive schemes to induce changes in business, household and individual behavior; and labor-intensive approaches rather than mechanization and massive capital investment. Such policies were officially adopted in the 1970s by Jaime Lerner, a visionary mayor who was also an architect and planner, and have helped pre-empt the usual growth-related problems faced by comparable cities. Among Curitiba's innovative features are: ·

- transport — an express bus-based transportation system, designed for speed and convenience which is also self financing, affordable, wheelchair-accessible, and offers balanced routes;
- solid waste — a garbage-purchase programme which pays low-income families in bus tokens or food in exchange for waste; more than 70% of households also sort recyclable materials for collection;
- housing — a low-income housing programme with ready access to jobs in Curitiba's Industrial City (which generates one-fifth of all jobs in the city; polluting industries are not allowed).
- incentives — provision of public information about land to fight land speculation;

- environmental education — free, practical short courses for workers and residents on the environmental implications of their work are offered by Curitiba's Free University for the Environment.

# 17.6 Resources

## Summary

Urbanization is the study of the social, political, and economic relationships in cities. There are three prerequisites for the development of a city. First, good environment with fresh water and a favorable climate; second, advanced technology, which will produce a food surplus to support non-farmers; and third, strong social organization to ensure social stability and a stable economy. Urbanization levels are affected by two things – migration and natural increase. Global urbanization reached the 50 percent mark in 2008, meaning that more than half of the global population was living in cities compared to only 30 percent 50 years ago. The access to basic services—clean water, sanitation, electricity, and roads—are some of the main urbanization challenges facing the developing world. Long commute times, observed in sprawling metropolitan areas are unsustainable from many aspects. Various negative health and environmental consequences can be identified related to these development trends. Green urbanism is a conceptual model that seeks to transform and re-engineer existing city districts and regenerate the post-industrial city center. It promotes the development of socially and environmentally sustainable city districts. The principles of green urbanism offer practical steps on the path to sustainable cities, harmonizing growth and usage of resources.

## Review Questions

1. Select an aspect of your day-to-day existence that has environmental consequences. Describe the environmental consequences, and briefly discuss more sustainable alternatives.
2. Describe a sustainable neighborhood that you're familiar with and explain what makes it sustainable.
3. Briefly describe a path to reducing our dependency on fossil fuels for transportation energy consumption.
4. What are the positive and negative impacts that buildings have on the environment and society?
5. Explain the connections between the design of our cities and resource use.

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