FRIEDLAND and RELYEA

Environmental Science for AP®

SECOND EDITION

College Board AP® Topic Outline	Friedland and Relyea: Environmental Science for AP®
I. Earth Systems and Resources (10–15%)	
A. Earth Science Concepts	Chapter 1 Studying the State of Our Earth Chapter 2 Environmental Systems
B. The Atmosphere	Chapter 3 Ecosystem Ecology Chapter 4 Global Climates and Biomes
C. Global Water Resources and Use	Chapter 9 Water Resources
D. Soil and Soil Dynamics	Chapter 8 Earth Systems
II. The Living World (10–15%)	
A. Ecosystem Structure	Chapter 3 Ecosystem Ecology Chapter 5 Evolution of Biodiversity
B. Energy Flow	Chapter 3 Ecosystem Ecology
C. Ecosystem Diversity	Chapter 6 Population and Community Ecology
D. Natural Ecosystem Change	Chapter 3 Ecosystem Ecology Chapter 5 Evolution of Biodiversity
E. Natural Biogeochemical Cycles	Chapter 3 Ecosystem Ecology Chapter 4 Global Climates and Biomes
III. Population (10–15%)	
A. Population Biology Concepts	Chapter 6 Population and Community Ecology
B. Human Population	Chapter 7 The Human Population
IV. Land and Water Use (10–15%)	
A. Agriculture	Chapter 10 Land, Public and Private Chapter 11 Feeding the World
B. Forestry	Chapter 10 Land, Public and Private
C. Rangelands	Chapter 10 Land, Public and Private
D. Other Land Use	Chapter 10 Land, Public and Private
E. Mining	Chapter 8 Earth Systems
F. Fishing	Chapter 11 Feeding the World
G. Global Economics	Chapter 20 Sustainability, Economics, and Equity
V. Energy Resources and Consumption (10–15%)	
A. Energy Concepts	Chapter 12 Nonrenewable Energy Sources
B. Energy Consumption	Chapter 12 Nonrenewable Energy Sources
C. Fossil Fuel Resources and Use	Chapter 12 Nonrenewable Energy Sources
D. Nuclear Energy	Chapter 12 Nonrenewable Energy Sources
E. Hydroelectric Power	Chapter 12 Nonrenewable Energy Sources
F. Energy Conservation	Chapter 13 Achieving Energy Sustainability
G. Renewable Energy	Chapter 13 Achieving Energy Sustainability
VI. Pollution (25–30%)	
A. Pollution Types	Chapter 14 Water Pollution Chapter 15 Air Pollution and Stratospheric Ozone Depletion Chapter 16 Waste Generation and Waste Disposal
B. Impacts on the Environment and Human Health	Chapter 14 Water Pollution Chapter 15 Air Pollution and Stratospheric Ozone Depletion Chapter 16 Waste Generation and Waste Disposal Chapter 17 Human Health and Environmental Risks
C. Economic Impacts	Chapter 14 Water Pollution Chapter 15 Air Pollution and Stratospheric Ozone Depletion Chapter 16 Waste Generation and Waste Disposal
VII. Global Change (10–15%)	
A. Stratospheric Ozone	Chapter 15 Air Pollution and Stratospheric Ozone Depletion
B. Global Warming	Chapter 19 Global Change
C. Loss of Biodiversity	Chapter 18 Conservation of Biodiversity

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Rensselaer Polytechnic Institute

FREEMAN

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To Katie, Jared, and Ethan
for their interest and enthusiasm.

—AJF

To Christine, Isabelle, and Wyatt for their
patience and inspiration.

—RAR

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About the Authors

Nancy Nutile-McMenemy

Brian Mattes

Andrew Friedland is Richard and Jane Pearl Professor in Environmental Studies and former chair of the Environmental Studies Program at Dartmouth College. He was the founding chair of the Advanced Placement Test Development Committee (College Board) for Environmental Science. He has a strong interest in high school science education, and in the early years of AP® environmental science he participated in many trainer and teacher workshops. For more than 10 years, Andy has been a guest lecturer at the St. Johnsbury Academy Advanced Placement Institute for Secondary Teachers. He has also served on the College Board AP® Environmental Science Curriculum Development and Assessment Committee.

Andy regularly teaches introductory environmental science and energy courses at Dartmouth and has taught courses in forest biogeochemistry, global change, and soil science, as well as foreign study courses in Kenya. Beginning in 2015, Andy brings his introductory environmental science course to the massive, open, online course format through the DartmouthX platform.

Andy received a BA degree in both biology and environmental studies, and a PhD in earth and environmental science, from the University of Pennsylvania. For more than three decades, Andy has been investigating the effects of air pollution on the cycling of carbon, nitrogen, and lead in high-elevation forests of New England and the Northeast. Recently, he has been examining the impact of increased demand for wood as a fuel, and the subsequent effect on carbon stored deep in forest soils.

Andy has served on panels for the National Science Foundation, USDA Forest Service, and Science Advisory Board of the Environmental Protection Agency. He has authored or coauthored more than 65 peer-reviewed publications and one book, *Writing Successful Science Proposals* (Yale University Press).

Andy is passionate about saving energy and has pursued many energy efficiency endeavors in his home. Recently, he installed a 4 kW solar photovoltaic tracker that follows the Sun during the day.

Rick Relyea is the David Darrin Senior '40 Endowed Chair in Biology and the executive director of the Darrin Freshwater Institute at Rensselaer Polytechnic Institute. Rick teaches courses in ecology, evolution, and animal behavior at the undergraduate and graduate levels. He received a BS in environmental forest biology from the State University of New York College of Environmental Science and Forestry, an MS in wildlife management from Texas Tech University, and a PhD in ecology and evolution from the University of Michigan.

Rick is recognized throughout the world for his work in the fields of ecology, evolution, animal behavior, and ecotoxicology. He has served on multiple scientific panels for the National Science Foundation and has been an associate editor for the journals of the Ecological Society of America. For two decades, he has conducted research on a wide range of topics, including predator-prey interactions, phenotypic plasticity, eutrophication of aquatic habitats, sexual selection, disease ecology, long-term dynamics of populations and communities across the landscape, and pesticide impacts on aquatic ecosystems. He has authored more than 110 scientific articles and book chapters, and has presented research seminars throughout the world. Rick recently moved to Rensselaer from the University of Pittsburgh, where he was named the Chancellor's Distinguished Researcher in 2005 and received the Tina and David Bellet Teaching Excellence Award in 2014.

Rick has a strong interest in high school education. High school science teachers conduct research in his laboratory and he offers summer workshops for high school teachers in the fields of ecology, evolution, and ecotoxicology. Rick also works to bring cutting-edge research experiments into high school classrooms.

Rick's commitment to the environment extends to his personal life. He lives in a home constructed with a passive solar building design and equipped with active solar panels on the roof. The solar panels generate so much electricity that he sells the extra electricity back to the local electric utility every month.

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From Andy Friedland . . .

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From Rick Relyea . . .

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Getting the Most from This Book

Daily life is filled with decisions large and small that affect our environment. From the food we eat, to the cars we drive or choose not to drive, to the chemicals we put into the water, soil, and air. The impact of human activity is wide-ranging and deep. And yet making decisions about the environment is often not easy or straightforward. Is it better for the environment if we purchase a new, energy-efficient hybrid car or should we continue using the older car we already own? Should we remove a dam that provides electricity for 70,000 homes because it interferes with the migration of salmon? Are there alternatives to fossil fuel for heating our homes?

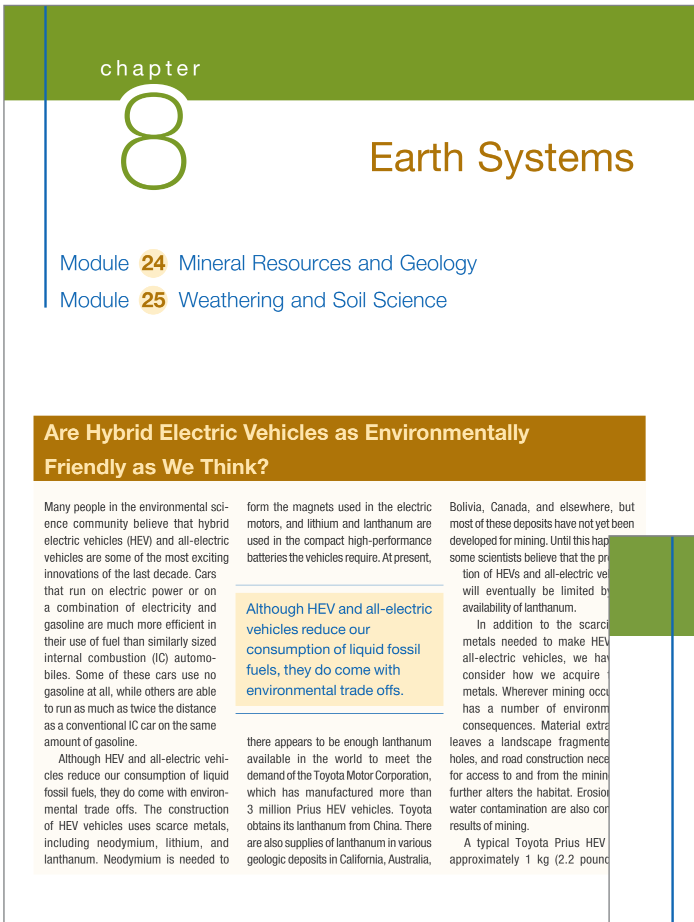
The purpose of this book is to give you a working knowledge of the big ideas of environmental science and help you to prepare for the AP® Environmental Science Exam. The book is designed to provide you with a strong foundation in the scientific fundamentals, to introduce you to the policy issues and conflicts that emerge in the real world, and to offer you an in-depth exploration of all the topics covered on the advanced placement exam in environmental science.

Like the first edition, *Friedland and Relyea Environmental Science for AP®*, Second Edition, is organized to closely follow the AP® environmental science course description. Every item on the College Board's "Topic Outline" is covered thoroughly in the text. Look inside the front cover for a detailed alignment guide. The textbook offers comprehensive coverage of all required AP® course topics and will help you prepare for success on the exam by:

- providing chapter opening case studies that will help you to see how environmental science is grounded in your daily life and in the world around you
- dividing each chapter into manageable modules that will help you to be organized and keep up with the challenging pace of the AP® environmental science course
- using the same terminology, language, and formulas that you will see on the AP® environmental science exam
- using expertly selected and artistically rendered figures, photographs, graphs, and visuals that will help you to understand and remember the big ideas and important concepts that will be on the exam
- providing you with many opportunities to practice for the exam throughout the year, including end-of-module AP® review questions, chapter AP® practice exams, unit AP® practice exams, and a cumulative AP® practice exam at the end

The next few pages offer you a brief tour of the features of this book that have been designed to help you succeed in the course and on the exam.

Explore the world around you through science.



chapter 8

Earth Systems

Are Hybrid Electric Vehicles as Environmentally Friendly as We Think?

Many people in the environmental science community believe that hybrid electric vehicles (HEV) and all-electric vehicles are some of the most exciting innovations of the last decade. Cars that run on electric power or on a combination of electricity and gasoline are much more efficient in their use of fuel than similarly sized internal combustion (IC) automobiles. Some of these cars use no gasoline at all, while others are able to run as much as twice the distance as a conventional IC car on the same amount of gasoline.

Although HEV and all-electric vehicles reduce our consumption of liquid fossil fuels, they do come with environmental trade offs. The construction of HEV vehicles uses scarce metals, including neodymium, lithium, and lanthanum. Neodymium is needed to form the magnets used in the electric motors, and lithium and lanthanum are used in the compact high-performance batteries the vehicles require. At present,

> Although HEV and all-electric vehicles reduce our consumption of liquid fossil fuels, they do come with environmental trade offs.

there appears to be enough lanthanum available in the world to meet the demand of the Toyota Motor Corporation, which has manufactured more than 3 million Prius HEV vehicles. Toyota obtains its lanthanum from China. There are also supplies of lanthanum in various geologic deposits in California, Australia, Bolivia, Canada, and elsewhere, but most of these deposits have not yet been developed for mining. Until this hap some scientists believe that the pr tion of HEVs and all-electric ve will eventually be limited b availability of lanthanum.

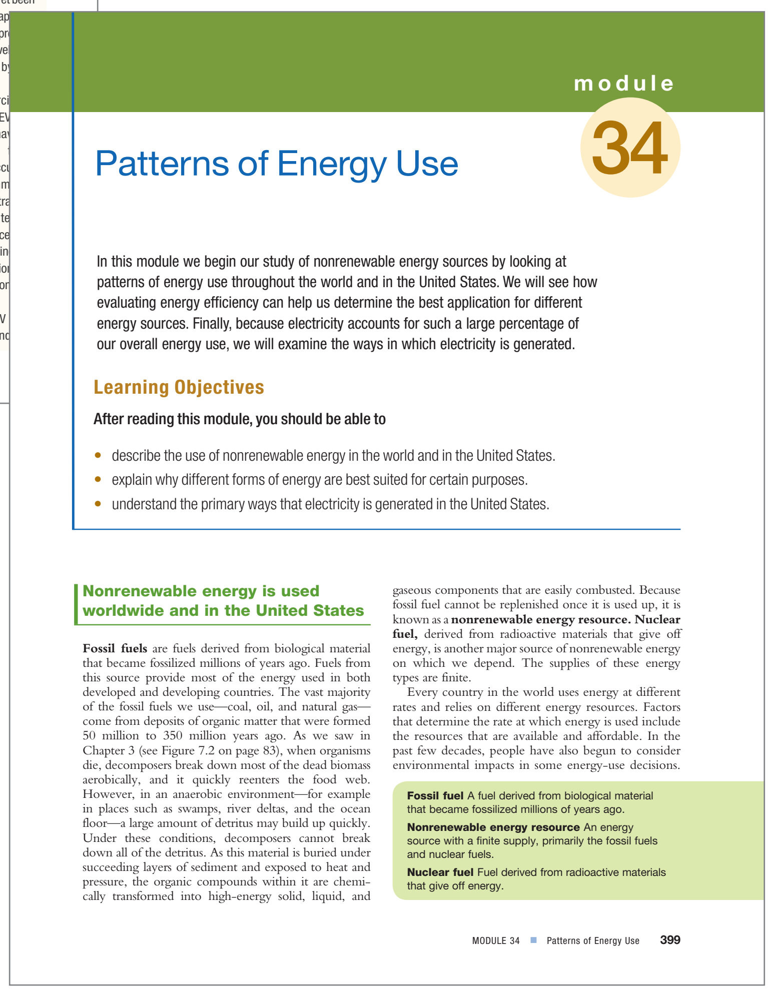
In addition to the scarci metals needed to make HEV all-electric vehicles, we ha consider how we acquire metals. Wherever mining occ has a number of environm consequences. Material extra leaves a landscape fragmente holes, and road construction nece for access to and from the minin further alters the habitat. Erosio water contamination are also co results of mining.

A typical Toyota Prius HEV approximately 1 kg (2.2 poun

Chapter Opening Case Study

Read the intriguing case study that begins each chapter and think about the environmental challenges and trade-offs that are introduced. The subjects of these studies often will spark spirited class discussion.

As you can see from case studies like this one from Chapter 8, it's not always easy to make sustainable choices.



module 34

Patterns of Energy Use

In this module we begin our study of nonrenewable energy sources by looking at patterns of energy use throughout the world and in the United States. We will see how evaluating energy efficiency can help us determine the best application for different energy sources. Finally, because electricity accounts for such a large percentage of our overall energy use, we will examine the ways in which electricity is generated.

Learning Objectives

After reading this module, you should be able to

- describe the use of nonrenewable energy in the world and in the United States.
- explain why different forms of energy are best suited for certain purposes.
- understand the primary ways that electricity is generated in the United States.

Nonrenewable energy is used worldwide and in the United States

Fossil fuels are fuels derived from biological material that became fossilized millions of years ago. Fuels from this source provide most of the energy used in both developed and developing countries. The vast majority of the fossil fuels we use—coal, oil, and natural gas—come from deposits of organic matter that were formed 50 million to 350 million years ago. As we saw in Chapter 3 (see Figure 7.2 on page 83), when organisms die, decomposers break down most of the dead biomass aerobically, and it quickly reenters the food web. However, in an anaerobic environment—for example in places such as swamps, river deltas, and the ocean floor—a large amount of detritus may build up quickly. Under these conditions, decomposers cannot break down all of the detritus. As this material is buried under succeeding layers of sediment and exposed to heat and pressure, the organic compounds within it are chemically transformed into high-energy solid, liquid, and gaseous components that are easily combusted. Because fossil fuel cannot be replenished once it is used up, it is known as a **nonrenewable energy resource. Nuclear fuel,** derived from radioactive materials that give off energy, is another major source of nonrenewable energy on which we depend. The supplies of these energy types are finite.

Every country in the world uses energy at different rates and relies on different energy resources. Factors that determine the rate at which energy is used include the resources that are available and affordable. In the past few decades, people have also begun to consider environmental impacts in some energy-use decisions.

Fossil fuel A fuel derived from biological material that became fossilized millions of years ago.

Nonrenewable energy resource An energy source with a finite supply, primarily the fossil fuels and nuclear fuels.

Nuclear fuel Fuel derived from radioactive materials that give off energy.

MODULE 34 ■ Patterns of Energy Use 399

Module Structure

Chapters are divided into short Modules to help keep you on pace. Each module opens with a brief description of what topics will be covered.

Learning Objectives

A list key ideas at the beginning of the module help to keep you focused as you read.

Running glossary

Important key terms are set in bold type in the text and defined at the bottom of the page on which they are introduced. Key terms are also defined in the glossary at the end of the book.

Math practice makes perfect.

Do the Math

Among the biggest challenges on the AP® Environmental Science Exam are questions that ask you to solve environmental science math problems. "Do the Math" problems help you practice the math skills that you'll need to tackle these problems on the exam.

do the math

Calculating Energy Supply

According to the U.S. Department of Energy, a typical home in the United States uses approximately 900 kWh of electricity per month. On an annual basis, this is

$$900 \text{ kWh/month} \times 12 \text{ months/year} = 10{,}800 \text{ kWh/year}$$

How many homes can a 500 MW power plant with a 0.9 capacity factor support? Begin by determining how much electricity the plant can provide per month:

$$500 \text{ MW} \times 24 \text{ hours/day} \times 30 \text{ days/month} \times 0.9 = 324{,}000 \text{ MWh/month}$$

1 MWh equals 1,000 kWh, so to convert MWh per month into kWh per month, we multiply by 1,000:

$$324{,}000 \text{ MWh/month} \times 1{,}000 \text{ kWh/MWh} = 324{,}000{,}000 \text{ kWh/month}$$

So

$$\frac{324{,}000{,}000 \text{ kWh/month}}{900 \text{ kWh/month/home}} = 360{,}000 \text{ homes}$$

On average, a 500 MW power plant can supply roughly 360,000 homes with electricity.

Your Turn During summer months, in hot regions of the United States, some homes run air conditioners continuously. How many homes can the same power plant support if average electricity usage increases to 1,200 kWh/month during summer months?

Your Turn

Each "Do the Math" box has a "Your Turn" practice problem to help you review and practice the math skills introduced.

do the math

Converting Between Hectares and Acres

In the metric system, land area is expressed in hectares. A hectare (ha) is 100 meters by 100 meters. In the United States, land area is most commonly expressed in acres. There are 2.47 acres in 1 ha. The conversion from hectares is relatively easy to do without a calculator; rounding to two significant figures gives us 2.5 acres in 1 ha. If a nature preserve is 100 ha, what is it size in acres?

$$100 \text{ ha} \times 2.5 \text{ acres} = 250 \text{ acres}$$

Your Turn A particular forest is 10,000 acres. Determine its size in hectares.

Prepare for the Exam

Once you are comfortable with the math skills introduced, you'll be prepared for quantitative problems on the exam.

Analyze and interpret visual data.

(a) Random distribution

(b) Uniform distribution

Photos and Illustrations

The photos and illustrations in this book are more than just pretty pictures. They have been carefully chosen and developed to help you comprehend and remember the key ideas.

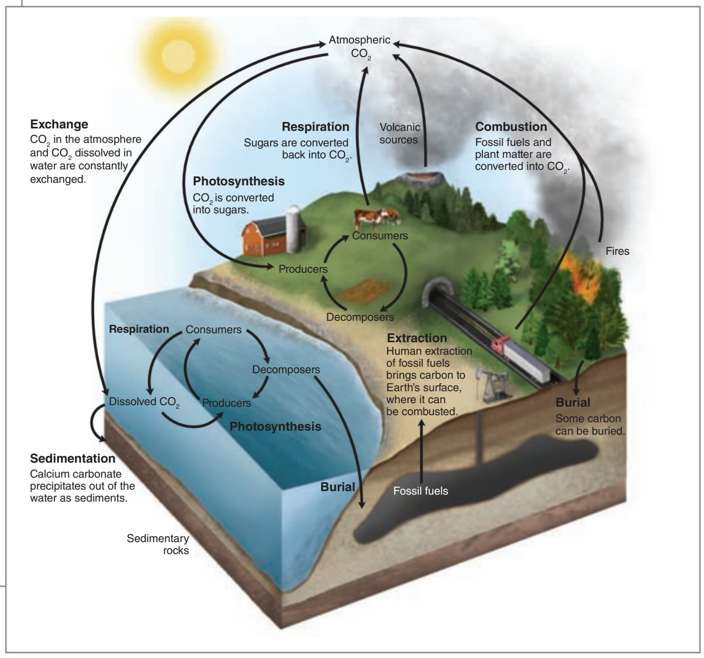


TABLE 36.1 Comparison of nonrenewable energy fuels

Energy Type	Advantages	Disadvantages	Pollutant and greenhouse gas emissions	Electricity (cents/kWh)	Energy return on energy investment*
Oil/gasoline	• Ideal for mobile combustion (high energy/mass ratio) • Quick ignition/turn-off capability • Cleaner burning than coal	• Significant refining required • Oil spill potential effect on habitats near drilling sites • Significant dust and emissions from fossil fuels used to power earth-moving equipment • Human rights/environmental justice issues in developing countries that export oil • Will probably be much less available in the next 40 years or so	• Second highest emitter of CO_2 among fossil fuels • Hydrocarbons • Hydrogen sulfide	• Relatively little electricity is generated from oil	4.0 (gasoline) 5.7 (diesel)
Coal	• Energy-dense and abundant—U.S. resources will last at least 200 years • No refining necessary • Easy, safe to transport • Economic backbone of some small towns	• Mining practices frequently risk human lives and dramatically alter natural landscapes • Coal power plants are slow to reach full operating capacity • A large contributing factor to acid rain in the United States	• Highest emitter of CO_2 among energy sources • Sulfur • Trace amounts of toxic metals such as mercury	5 cents/kWh	14
Natural Gas	• Cogeneration power plants can have efficiencies up to 60% • Efficient for cooking, home heating, etc. • Fewer impurities than coal or oil	• Risk of leaks/explosions • Twenty-five times more effective as a greenhouse gas than CO_2 • Not available everywhere because it is transported by pipelines	• Methane • Hydrocarbons • Hydrogen sulfide	6–8 cents/kWh	8
Nuclear Energy	• Emits no CO_2 once plant is operational • Offers independence from imported oil • High energy density, ample supply	• Very unpopular; generates protests • Plants are very expensive to build because of legal challenges • Meltdown could be catastrophic • Possible target for terrorist attacks	• Radioactive waste is dangerous for hundreds of thousands of years • No long-term plan currently in place to manage radioactive waste • No air pollution during production	12–15 cents/kWh	8

MODULE 36 ■ Nuclear Energy Resources 424

*Estimates vary widely.

Tables and Graphs

To understand environmental science and succeed on the exam, you need to engage in the scientific practice of analyzing and interpreting a variety of tables, graphs, and charts.

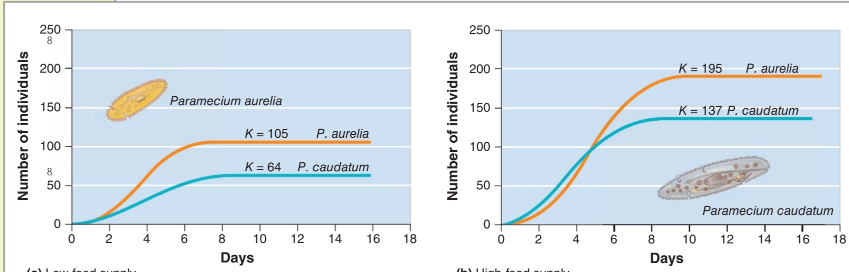


FIGURE 18.3 Gause's experiments. (a) Under low-food conditions, the population sizes of two species of *Paramecium* initially increased rapidly, but then leveled off as their food supply became limiting. (b) When twice as much food was provided, both species attained population sizes that were nearly twice as large, but they again leveled off. *(Data from Gause, 1932)*

Review and practice for quizzes and tests.

module 3

REVIEW

In this module, we have seen how specific aspects of the scientific method are used to conduct field and laboratory evaluations of how human activity affects the natural environment. The scientific method follows a process of observations and questions, testable hypotheses and predictions, and data collection. Results are interpreted and shared with other researchers. Experiments can be either controlled (manipulated) experiments or natural experiments that make use of natural events. There are often challenges in environmental science including the lack of baseline data and the interactions with social factors such as human preferences.

Module 3 AP® Review Questions

1. The first step in the scientific process is
   (a) collecting data.
   (b) observations and questions.
   (c) forming a hypothesis.
   (d) disseminating findings.
   (e) forming a theory.

Use the following information for questions 2 and 3:
Two new devices for measuring lead contamination in water are tested for accuracy. Scientists test each device with seven samples of water known to contain 400 ppm of lead. Their data is shown below. Concentration is in parts per billion.

Water Sample	1	2	3	4	5	6	7
Device 1	415	417	416	417	415	416	416
Device 2	398	401	400	402	398	400	399

2. The data from device 1 is
   (a) accurate, but not precise.
   (b) precise, but not accurate.
   (c) both accurate and precise.
   (d) neither accurate nor precise.
   (e) not clear enough to support any conclusion about accuracy or precision.

3. Assuming the devices were used correctly, and assuming we want to choose a device that accurately reflects the true concentration of lead in the water samples, which conclusion does the data support?
   (a) Device 1 is superior to device 2 because it is more precise.
   (b) Device 2 is superior to device 1 because it is more precise.
   (c) Device 1 is superior to device 2 because it is more accurate.
   (d) Device 2 is superior to device 1 because it is more accurate.
   (e) Both devices are equally effective at measuring contaminates.

4. Challenges in the study of environmental science include all of the following except
   (a) dangers of studying natural systems.
   (b) lack of baseline data.
   (c) subjectivity of environmental impacts.
   (d) complexity of natural systems.
   (e) complex interactions between humans and the environment.

5. A control group is
   (a) a group with the same conditions as the experimental group.
   (b) a group with conditions found in nature.
   (c) a group with a randomly assigned population.
   (d) a group with the same conditions as the experimental group except for the study variable.
   (e) a group that is kept at the same conditions throughout the experiment

Module Review

Solidify your understanding by reviewing the main ideas in each module review.

Exam Prep All Year

Each module ends with multiple-choice questions similar to those on the AP® exam. Practicing your test-taking strategies for multiple-choice questions throughout the year will pay off when you take the exam.

Chapter Review

At the end of each chapter, take time to review the main ideas and key terms.

chapter 1

REVIEW

Throughout this chapter, we have outlined principles, techniques, and methods that will allow us to approach environmental science from an interdisciplinary perspective as we evaluate the current condition of Earth and the ways that human beings have influenced it. We identified that we can use environmental indicators to show the status of specific environmental conditions in the past, at present, and, potentially, into the future. These indicators and other environmental metrics must be measured using the same scientific process used in other fields of science. Environmental science does contain some unique challenges because there is no undisturbed baseline—humans began manipulating Earth long before we have been able to study it.

Key Terms

Fracking
Environment
Environmental science
Ecosystem
Biotic
Abiotic
Environmentalist
Environmental studies
Ecosystem services
Environmental indicators
Biodiversity
Genetic diversity
Species
Species diversity
Speciation
Background extinction rate
Greenhouse gases
Anthropogenic
Development
Sustainability
Sustainable development
Biophilia
Ecological footprint
Scientific method
Hypothesis
Null hypothesis
Replication
Sample size
Accuracy
Precision
Uncertainty
Theory
Control group
Natural experiment

Learning Objectives Revisited

Module 1 Environmental Science

- **Define the field of environmental science and discuss its importance.**
  Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.
- **Identify ways in which humans have altered and continue to alter our environment.**
  The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

Module 2 Environmental Indicators and Sustainability

- **Identify key environmental indicators and their trends over time.**
  Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric CO_2 concentrations, human population, and resource depletion. Biological diversity is decreasing as a result of human actions, most notably habitat destruction and habitat degradation. Food production appears to be leveling off and may be decreasing. Carbon dioxide concentrations are steadily increasing as a result of fossil fuel combustion and land conversion. Human population continues to increase and probably will continue to do so throughout this century. Resource depletion for most natural resources continues to increase.

Learning Objectives Revisited

Check your notes against summaries of the learning objectives for each module in the chapter.

Prepare and practice for the AP® Environmental Science Exam.

Chapter AP® Environmental Science Practice Exam

When you finish a chapter take the practice exam to check your understanding of the main ideas. The practice exam will help you become familiar with the style of questions on he AP® Environmental Science Exam.

Chapter 1 AP® Environmental Science Practice Exam

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–11.

1. Which of the following events has increased the impact of humans on the environment?
   I. advances in technology
   II. reduced human population growth
   III. use of tools for hunting

   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. As described in this chapter, environmental indicators
   (a) always tell us what is causing an environmental change.
   (b) can be used to analyze the health of natural systems.
   (c) are useful only when studying large-scale changes.
   (d) do not provide information regarding sustainability.
   (e) take into account only the living components of ecosystems.

3. Which statement regarding a global environmental indicator is NOT correct?
   (a) Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
   (b) World grain production has increased fairly
   (c) For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
   (d) World population is expected to be between 8.1 billion and 9.6 billion by 2050.
   (e) Some natural resources are available in finite amounts and are consumed during a one-time use, whereas other finite resources can be used multiple times through recycling.

4. Figure 2.5 (on page 12) shows atmospheric carbon dioxide concentrations over time. The measured concentration of CO_2 in the atmosphere is an example of
   (a) a sample of air from over the Antarctic.
   (b) an environmental indicator.
   (c) replicate sampling.
   (d) calculating an ecological footprint.
   (e) how to study seasonal variation in Earth's temperatures.

5. Environmental metrics such as the ecological footprint are most informative when they are considered along with other environmental indicators. Which indicator, when considered in conjunction with the ecological footprint, would provide the most information about environmental impact?
   (a) biological diversity
   (b) food production
   (c) human population
   (d) CO_2
   (e) water

6. In science

Multiple-Choice Questions

Each chapter exam begins with multiple-choice questions modeled after those you'll see on the exam. Many of the questions ask you to analyze or interpret tables, graphs, or figures.

Section 2: Free-Response Questions

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

1. Your neighbor has fertilized her lawn. Several weeks later, she is alarmed to see that the surface of her ornamental pond, which sits at the bottom of the sloping lawn, is covered with a green layer of algae.
   (a) Suggest a feasible explanation for the algal bloom in the pond. (2 points)
   (b) Design an experiment that would enable you to validate your explanation. Include and label in your answer:
      (i) a testable hypothesis (2 points)
      (ii) the variable that you will be testing (1 point)
      (iii) the data to be collected (1 point)
      (iv) a description of the experimental procedure (2 points)
      (v) a description of the results that would validate your hypothesis (1 point)
   (c) Based on the data from your experiment and your explanation of the problem, think of and suggest one action that your neighbor could take to help the pond recover. (1 point)

Free-Response Questions

Chapter exams include two free-response questions. Points are assigned to indicate how a complete, correct answer would be scored on the AP® exam. The more practice you have in writing answers to free-response questions, the better you will do on the exam.

Unit AP® Environmental Science Practice Exam

The textbook is divided into 8 major units. At the end of each unit, you are provided with a longer practice exam containing 20 multiple-choice questions and 2 free-response questions. These exams give you a chance to review material across multiple chapters and to practice your test-taking skills.

Unit 1 AP® Environmental Science Practice Exam

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–20.

1. Which best describes how humans have altered natural systems?
   I. Overhunted many large mammals to extinction.
   II. Created habitat for species to thrive.
   III. Emitted greenhouse gases.
   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. Which does NOT describe a benefit of biodiversity?
   (a) Genetic biodiversity improves the ability of a population to cope with environmental change.
   (b) Ecosystems with higher species diversity are more productive.
   (c) Species serve as environmental indicators of global-scale problems.
   (d) Speciation reduces natural rates of species extinction.
   (e) Humans rely on ecological interactions among species to produce ecosystem services.

3. Which of the following is NOT a consequence of human population growth?
   (a) Depletion of natural resources

6. The greatest value of the scientific method is best stated as:
   (a) The scientific method permits researchers a rapid method of disseminating findings.
   (b) The scientific method removes bias from observation of natural phenomenon.
   (c) The scientific method allows findings to be reproduced and tested.
   (d) The scientific method promotes sustainable development.
   (e) The scientific method reduces the complexity of experimental results.

7. Researchers conducted an experiment to test the hypothesis that the use of fertilizer near wetlands is associated with increased growth of algae. An appropriate null hypothesis would be:
   (a) The use of fertilizer near wetlands is associated with an increase in fish biomass.
   (b) Growth of algae in wetlands is never associated with increased fertilizer use.
   (c) Application of fertilizers near wetlands is always associated with increased growth of algae.
   (d) Fertilizer use near wetlands has no association with growth of algae.
   (e) Fertilizer use near wetlands leads to increased growth of algae as a result of elevated nutrient concentrations.

Cumulative AP® Environmental Science Practice Exam

At the end of the text you will find a cumulative exam with 100 multiple-choice questions and 4 free-response questions. This exam matches the actual AP® Environmental Science exam in length and scope.

cumulative AP® environmental science practice exam

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–100.

1. Primary production is an example of
   I. an ecosystem service.
   II. an environmental indicator.
   III. heterotrophic activity.
   (a) I only
   (b) II only
   (c) I and II
   (d) II and III
   (e) I, II, and III

2. Which of the following is likely to increase biodiversity within a biome?
   (a) Landscape fragmentation
   (b) Introduction of an invasive species
   (c) Immigration of humans
   (d) Speciation
   (e) A disease epidemic

3. The United States produces 8 million tons of oranges in a single year. However, many orange crops are succumbing to a deadly invasive bacteria. If 10,000 hectares of orange cropland are lost in a year to this bacteria, and a single acre can produce 20 tons of oranges, what percentage of the total orange crop is lost to the disease in a year? (Note that 1 hectare = 2.5 acres.)
   (a) 2 percent
   (b) 6 percent
   (c) 10 percent
   (d) 20 percent
   (e) 24 percent

4. Which is a flaw of this experiment?
   (a) The experiment lacks a control treatment.
   (b) 10 ppm is a negligible increase of CO_2 relative to ambient concentrations.
   (c) The hypothesis is actually a null hypothesis.
   (d) The measured response variable does not relate to the hypothesis.
   (e) N_2O gas is not a greenhouse gas.

5. As hypothesized, the researchers found that plants exposed to elevated CO_2 had increased biomass after 2

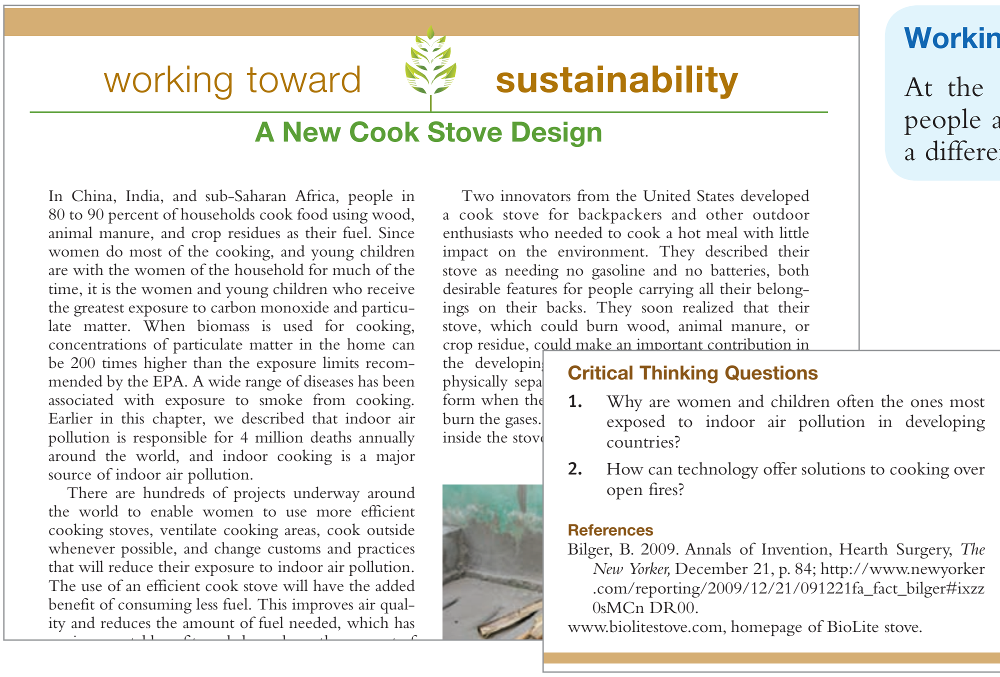
Section 2: Free-Response Questions

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

1. The City of Philadelphia recently replaced one out of every 10 trash bins with solar-powered trash compactors. The compactor is an enclosed unit with a door that opens for trash disposal. The compactor automatically detects when the bin is full and uses a solar-powered mechanical crusher to compact the contents. When the compactor needs to be emptied, it sends an electronic signal. Use of solar-powered compactors has increased the capacity of public trash bins and has reduced the number of trash collection visits to each bin from 17 times per week to 5 times per week.
   (a) Describe four positive externalities of installing solar-powered trash compactors. (2 points)
   (b) Describe six cradle-to-grave components of solar-powered trash compactors. (2 points)
   (c) Suggest one way that the installation of solar-powered trash compactors can reverse the effects of urban blight. (2 points)

2. The country of Costa Rica has an abundance of climactic, geographic, and biological diversity. However, in the last century intensive farming and population growth have led to a 75 percent reduction in its forests. In the 1980s, the government of Costa Rica began to address concerns about the loss of forest with a series of political and environmental programs. These programs, designed to generate more sustainable economic development, include land protection and conservation of biodiversity.
   (a) Costa Rica lies just north of the equator and contains a series of mountain ranges that run the entire length of the country.
      (i) Given its geographic location, what is likely to be the prevailing wind pattern across the country? (1 point)
      (ii) Describe how mountain ranges contribute to the climactic, geographic, and biological diversity observed in Costa Rica. (1 point)
   (b) Given that Costa Rica is bordered by the Atlantic and Pacific Oceans, how are weather patterns in the country likely to be affected by the El Niño–Southern Oscillation (ENSO)? (2 points)

Be inspired by individuals making a difference.



working toward sustainability

A New Cook Stove Design

In China, India, and sub-Saharan Africa, people in 80 to 90 percent of households cook food using wood, animal manure, and crop residues as their fuel. Since women do most of the cooking, and young children are with the women of the household for much of the time, it is the women and young children who receive the greatest exposure to carbon monoxide and particulate matter. When biomass is used for cooking, concentrations of particulate matter in the home can be 200 times higher than the exposure limits recommended by the EPA. A wide range of diseases has been associated with exposure to smoke from cooking. Earlier in this chapter, we described that indoor air pollution is responsible for 4 million deaths annually around the world, and indoor cooking is a major source of indoor air pollution.

There are hundreds of projects underway around the world to enable women to use more efficient cooking stoves, ventilate cooking areas, cook outside whenever possible, and change customs and practices that will reduce their exposure to indoor air pollution. The use of an efficient cook stove will have the added benefit of consuming less fuel. This improves air quality and reduces the amount of fuel needed, which has

Two innovators from the United States developed a cook stove for backpackers and other outdoor enthusiasts who needed to cook a hot meal with little impact on the environment. They described their stove as needing no gasoline and no batteries, both desirable features for people carrying all their belongings on their backs. They soon realized that their stove, which could burn wood, animal manure, or crop residue, could make an important contribution in the developin[g] physically sepa[rate] form when the burn the gases. inside the stov[e]

Critical Thinking Questions

1. Why are women and children often the ones most exposed to indoor air pollution in developing countries?
2. How can technology offer solutions to cooking over open fires?

References

Bilger, B. 2009. Annals of Invention, Hearth Surgery, *The New Yorker,* December 21, p. 84; http://www.newyorker.com/reporting/2009/12/21/091221fa_fact_bilger#ixzz0sMCn DR00.

www.biolitestove.com, homepage of BioLite stove.

Working Toward Sustainability

At the end of each chapter read about people and organizations that are making a difference.

Critical Thinking Questions

Working Toward Sustainability provides questions that give you a chance to hone your critical thinking and writing skills.

Science in the real world.

Tracy Packer Photography/Getty Images

1

science applied

What Happened to the Missing Salt?

At the beginning of the twentieth century, the City of Los Angeles needed more water for its inhabitants. As we saw at the beginning of Chapter 2, in 1913 the city designed a plan to redirect water away from Mono Lake in California. Before the Los Angeles Aqueduct was built, approximately 120 billion liters of stream water (31 billion gallons) flowed into Mono Lake in an average year. The City of Los Angeles altered the water balance of Mono Lake and at the same time caused a series of changes to the Mono Lake system that led to an increase in the salt concentration in Mono Lake.

water from streams must be equal to the outpu[t] through evaporation.

How did the salt balance change at Mono Lake?

Although we can make the assumption that in Mono Lake is in steady state in a typical salt balance in the lake is not. By applying so principles we have learned in the first two ch can make observations and draw conclusi what has probably happened at Mono L

Free-Response Question

Water that flows into Mono Lake contains a much smaller concentration of salt than the water already in the lake. This inflow tends to stratify, or float on top of existing water, because fresh water is less dense that salt water. As salt from the lower layer dissolves into the upper layer, nutrients from the bottom of the lake also rise to the surface. This exchange of nutrients is critical for the growth of algae in the surface waters. Recent research suggests that the reduction of water diversion from Mono Lake had unexpected results:

In 1995, the reduction of stream diversions from Mono Lake, combined with greater than average quantities of fresh water from snowmelt runoff, led to a rapid rise in water level. The large volume

Science Applied

At the end of each unit, the "Science Applied" feature offers you an opportunity to read about how the science you are learning is used to make decisions about environmental issues.

Practice Free-Response Questions

Science Applied includes a free-response question related to the topic in the article.

FRIEDLAND and RELYEA

Environmental Science for AP®

SECOND EDITION

A hydraulic fracturing site like this one near Canton, Pennsylvania, can contain many features that are seen prominently here including a concrete pad, a drilling rig, and many storage containers. *(Les Stone/Corbis)* chapter 1

Environmental Science: Studying the State of Our Earth

To Frack, Or Not to Frack

The United States—like other developed countries—is highly dependent on fuels such as coal and oil that come from the remains of ancient plants and animals. However, the use of these fossil fuels is responsible for many environmental problems that include land degradation and the release of pollutants into the air and water. Natural gas, also known as methane, is the least harmful producer of air pollution among the fossil fuels; it burns more completely and cleanly than coal or oil, and it contains fewer impurities.

Due to advances in technology, oil and mining companies have recently increased their reliance on *fracking*. **Fracking**, short for hydraulic fracturing, is a method of oil and gas extraction that uses high-pressure fluids to force open existing cracks in rocks deep underground. This technique allows extraction of natural gas from locations that were previously so difficult to reach that extraction was economically unfeasible. As a result, large quantities of natural gas are now available in the United States at a lower cost than before. A decade ago, 40 percent of energy in the United States was used to generate electricity with half of that energy coming from coal. As a result of fracking, electricity generation now uses less coal and more natural gas. Since coal emits more air pollutants—including carbon dioxide—than does natural gas, increased fracking initially appeared to be beneficial to the environment.

Footage of flames shooting from kitchen faucets became popular on YouTube.

Fracking Hydraulic fracturing, a method of oil and gas extraction that uses high-pressure fluids to force open cracks in rocks deep underground.

However, reports soon began appearing both in the popular press and in scientific journals about the negative consequences of fracking. Large amounts of water are used in the fracking process with millions of gallons of water taken out of local streams and rivers and pumped down into each gas well. A portion of this water is later removed from the well and must be properly treated after use to avoid contaminating local water bodies.

A variety of chemicals are added to the fracking fluid to facilitate the release of natural gas. Mining companies are not required to publicly identify all of these chemicals. Environmental scientists and concerned citizens began to wonder if fracking was responsible for chemical contamination of underground water and, in one case, the poisoning of livestock. Some drinking-water wells near fracking sites became contaminated with natural gas, and homeowners and public health officials asked if fracking was the culprit. Water with high concentrations of natural gas can be flammable, and footage of flames shooting from kitchen faucets after someone ignited the water became popular on YouTube, in documentaries, and in feature films. However, it wasn't clear if fracking caused natural gas to contaminate well water or if some of these wells contained natural gas long before fracking began. Several reputable studies showed that drinking-water wells near some fracking sites were contaminated, with natural gas concentrations in the nearby wells being much higher than in more distant wells. These issues need further study, which may take years.

Scientists have begun to assess how much natural gas escapes during the fracking and gas extraction process. As we will learn in Chapter 19, methane is a greenhouse gas and is much more efficient at trapping heat from Earth than carbon dioxide, which is the greenhouse gas most commonly produced by human activity. As the number of potential environmental issues associated with fracking began to increase, environmental scientists and activists began to ask whether fracking was making the greenhouse problem and other environmental problems worse. By 2014, it appeared that opponents of fracking were as numerous as supporters.

Certainly, using natural gas is better for the environment than coal, though using less fossil fuel—or using no fossil fuel at all—would be even better. However, at present it is difficult to know whether the benefits of using natural gas outweigh the problems that extraction causes. Many years may pass before the extent and nature of harm from fracking is known.

The story of natural gas fracking provides a good introduction to the study of environmental science. It shows us that human activities that are initially perceived as causing little harm to the environment can in fact have adverse effects, and that we may not recognize these effects until we better understand the science surrounding the issue. It also illustrates the difficulty in obtaining absolute answers to questions about the environment and demonstrates that environmental science can be controversial. Finally, it shows us that making assessments and choosing appropriate actions in environmental science are not always as clear-cut as they first appear.

Sources:

S. G. Osborn et al., Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing, *Proceedings of the National Academy of Sciences* 108 (2011): 8172–8176; Drilling down. Multiple authors in 2011 and 2012. *New York Times*, viewed at: http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html.

The process of scientific inquiry builds on previous work and careful, sometimes lengthy, investigations. For example, we will eventually accumulate a body of knowledge on the effects of hydraulic fracturing of natural gas, but until we have this knowledge, we will not be able to make a fully informed decision about the policies of energy extraction. In the meantime, we may need to make interim decisions based on incomplete information. This uncertainty is one feature—and an exciting aspect—of environmental science.

To investigate important topics such as the extraction and use of fossil fuels, environmental science relies on a number of indicators, methodologies, and tools. This chapter introduces you to the study of the environment and outlines some of the important foundations and assumptions you will use throughout your study.

module

1

Environmental Science

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, both large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

Learning Objectives

After reading this module you should be able to

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.

Environmental science offers important insights into our world and how we influence it

Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our **environment** is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin an examination of **environmental science,** the field of study that looks at interactions among human systems and those found in nature. By *system* we mean any set of interacting components that influence one another by exchanging energy or materials. We have already seen that a change in one part of a system—for example, fracking in a particular geologic formation—can cause changes throughout the entire system, such as in a nearby well that supplies drinking water.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist's work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or to even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The specific case of fracking at a particular location in the United States, for example, is a regional problem. Other environmental scientists

Environment The sum of all the conditions surrounding us that influence life.

Environmental science The field of study that looks at interactions among human systems and those found in nature.

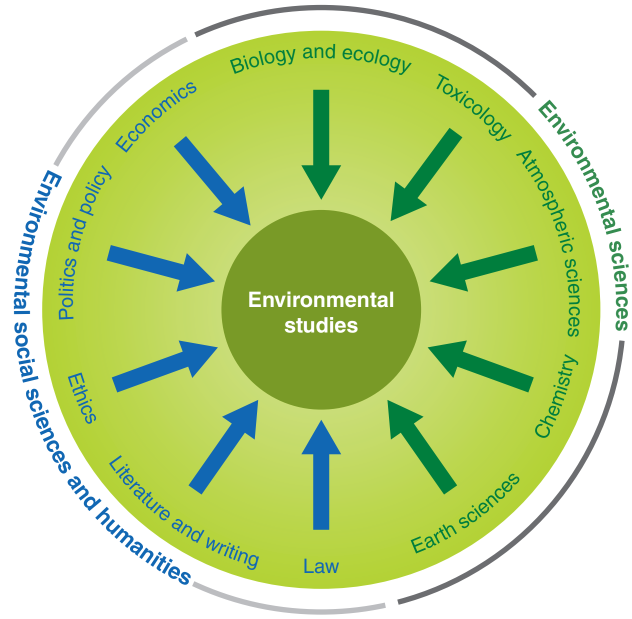


FIGURE 1.1 **Environmental studies.** The study of environmental science uses knowledge from many disciplines.

work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an *ecosystem*. An **ecosystem** is a particular location on Earth with interacting components that include living, or **biotic,** components and nonliving, or **abiotic,** components.

As a student of environmental science, you should recognize that environmental science is different from *environmentalism,* which is a social movement that seeks to protect the environment through lobbying, activism, and education. An **environmentalist** is a person who participates in environmentalism. In contrast, an environmental scientist, like any scientist, follows the process of observation, hypothesis testing, and field and laboratory research. We'll learn more about the process of science later in this chapter.

Ecosystem A particular location on Earth with interacting biotic and abiotic components.

Biotic Living.

Abiotic Nonliving.

Environmentalist A person who participates in environmentalism, a social movement that seeks to protect the environment through lobbying, activism, and education.

Environmental studies The field of study that includes environmental science and additional subjects such as environmental policy, economics, literature, and ethics.

So what does the study of environmental science actually include? As FIGURE 1.1 shows, environmental science encompasses topics from many scientific disciplines, such as chemistry, biology, and Earth science. Environmental science is itself a subset of the broader field known as **environmental studies,** which includes additional subjects such as environmental policy, economics, literature, and ethics. Throughout the course of this book you will become familiar with these and many other disciplines.

We have seen that environmental science is a deeply interdisciplinary field. It is also a rapidly growing area of study. As human activities continue to affect the environment, environmental science can help us understand the consequences of our interactions with our planet and help us make better decisions about our actions.

Humans alter natural systems

Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn't stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, biotic factors interact with abiotic factors to influence the future of the forest. All of these factors are part of a system.

Systems can vary in size. A large system may contain many smaller systems within it. FIGURE 1.2 shows an example of complex, interconnecting systems that operate at multiple space and time scales: the fisheries of the North Atlantic. A physiologist who wants to study how codfish survive in the North Atlantic's freezing waters must consider all the biological adaptations of the cod that enable it to be part of one system. In this case, the fish and its internal organs are the system being studied. In the same environment, a marine biologist might study the predator-prey relationship between cod and herring. That relationship constitutes another system, which includes two fish species and the environment they live in. At an even larger scale, a scientist might examine a system that includes all of these systems as well as people, fishing technology, policy, and law. The global environment is composed of both small-scale and large-scale systems.

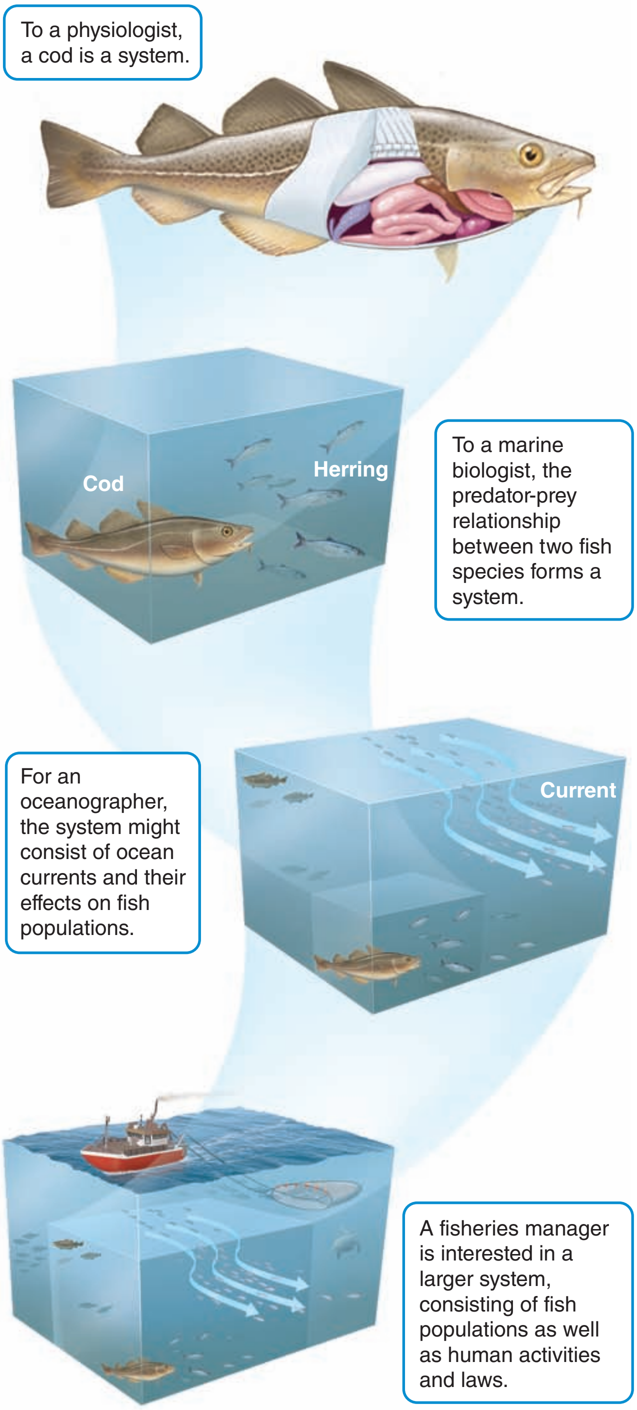


FIGURE 1.2 Systems within systems. The boundaries of an environmental system may be defined by the researcher's point of view. Physiologists, marine biologists, oceanographers, and fisheries managers would all describe the North Atlantic Ocean fisheries system differently.

Humans manipulate the systems in their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas. We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally—for example, by our activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that there are so many of us affects our surroundings.

Humans and our direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters; when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn't all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has substantially increased both the rate and the scale of our global environmental impact. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Because cities cover land that was once natural habitat, species that relied on that habitat must adapt, relocate, or go extinct. Human-induced changes in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not "kept up" and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal effects on the environment. But when roughly 4 million people live in a modern city like Los Angeles, their combined activity will cause environmental damage that will inevitably pollute the water, air, and soil as well as introduce other adverse consequences (FIGURE 1.3).

(a)

(b)

FIGURE 1.3 Human impact on Earth. It is impossible for millions of people to inhabit an area without altering it. (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2013, Los Angeles had a population of 3.9 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people.
(a: The Granger Collection, New York; b: LA/AeroPhotos/Alamy)

module 1

REVIEW

In this module we have seen that the study of environmental science helps us understand the role humans have played in the natural environment, and how that role has changed over time. There are specific approaches to the study of environmental science, some of which utilize terms and concepts from other disciplines. To study environmental science, we utilize specific techniques and environmental indicators, the focus of the next module.

Module 1 AP® Review Questions

1. Impacts of fracking include
   I contamination of ground water.
   II increased use of coal.
   III lower natural gas prices.
   (a) I only
   (b) I and II only
   (c) II and III only
   (d) I and III only
   (e) I, II, and III

2. Which of the following is an abiotic component?
   (a) an eagle
   (b) a rock
   (c) a tree
   (d) a human
   (e) a virus

3. Which of the following is NOT true about ecosystems?
   (a) They include biotic components.
   (b) They can be a wide range of sizes.
   (c) They include no human components.
   (d) Many interactions among species occur in them.
   (e) They include abiotic components.

4. Each of the following is an example of how humans have negatively affected the environment except
   (a) hunting large mammals.
   (b) conversion of arid land to agricultural use.
   (c) the use of fire to create the Great Plains.
   (d) slash-and-burn forest clearing.
   (e) fertilizer additions to lakes and rivers.

module

2

Environmental Indicators and Sustainability

As we study the way humans have altered the natural world, it is important to have techniques for measuring and quantifying human impact. Environmental indicators allow us to assess the impact of humans on Earth. The use of these indicators help us determine whether or not the quality of the natural environment is improving and inform discussions on the sustainability of humans on the planet.

Learning Objectives

After reading this module you should be able to

- identify key environmental indicators and their trends over time.
- define sustainability and explain how it can be measured using the ecological footprint.

Environmental scientists monitor natural systems for signs of stress

One critical question that environmental scientists investigate is whether the planet's natural life-support systems are being degraded by human-induced changes. Natural environments provide what we refer to as **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. Although we often take a healthy ecosystem for granted, we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems.

To describe the health and quality of natural systems, environmental scientists use *environmental indicators*. Just as body temperature and heart rate can indicate whether a person is healthy or sick, **environmental indicators** describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators and the chapters in which they are covered are listed in **TABLE 2.1**.

In this book we will focus on the five global-scale environmental indicators listed in **TABLE 2.2**: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the atmosphere, human population, and resource depletion. Throughout the text we will cover each of these five indicators in greater detail. Here we take a first look.

Ecosystem services The processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced.

Environmental indicator An indicator that describes the current state of an environmental system.

TABLE 2.1 Some common environmental indicators

Environmental indicator	Unit of measure	Chapter
Human population	Individuals	7
Ecological footprint	Hectares of land	1
Total food production	Metric tons of grain	11
Food production per unit area	Kilograms of grain per hectare of land	11
Per capita food production	Kilograms of grain per person	11
Carbon dioxide	Concentration in air (parts per million)	19
Average global surface temperature	Degrees centigrade	19
Sea level change	Millimeters	19
Annual precipitation	Millimeters	4
Species diversity	Number of species	5, 18
Fish consumption advisories	Present or absent; number of fish allowed per week	17
Water quality (toxic chemicals)	Concentration	14
Water quality (conventional pollutants)	Concentration; presence or absence of bacteria	14
Deposition rates of atmospheric compounds	Milligrams per square meter per year	15
Fish catch or harvest	Kilograms of fish per year or weight of fish per effort extended	11
Extinction rate	Number of species per year	5
Habitat loss rate	Hectares of land cleared or "lost" per year	18
Infant mortality rate	Number of deaths of infants under age 1 per 1,000 live births	7
Life expectancy	Average number of years an infant born today can be expected to live under current conditions	7

TABLE 2.2 Five key global indicators

Indicator	Recent trend	Outlook for the future	Overall impact on environmental quality
Biological diversity	Large number of extinctions, extinction rate increasing	Extinctions will continue	Negative
Food production	Per capita production possibly leveling off	Unclear	May affect the number of people Earth can support
Average global surface temperature and CO_2 concentration	CO_2 concentrations and temperatures increasing	Probably will continue to increase, at least in the short term	Effects are uncertain and varied but probably detrimental
Human population	Still increasing, but growth rate slowing	Population leveling off; resource consumption rates also a factor	Negative
Resource depletion	Many resources being depleted at rapid rate, but human ingenuity develops "new" resources, and efficiency of resource use is increasing in many cases	Unknown	Increased use of most resources has negative effects

Biological Diversity

Biological diversity, or **biodiversity,** is the diversity of life forms in an environment. It exists on three scales: *ecosystem, species,* and *genetic,* illustrated in FIGURE 2.1. Each level of biodiversity is an important indicator of environmental health and quality.

Genetic Diversity

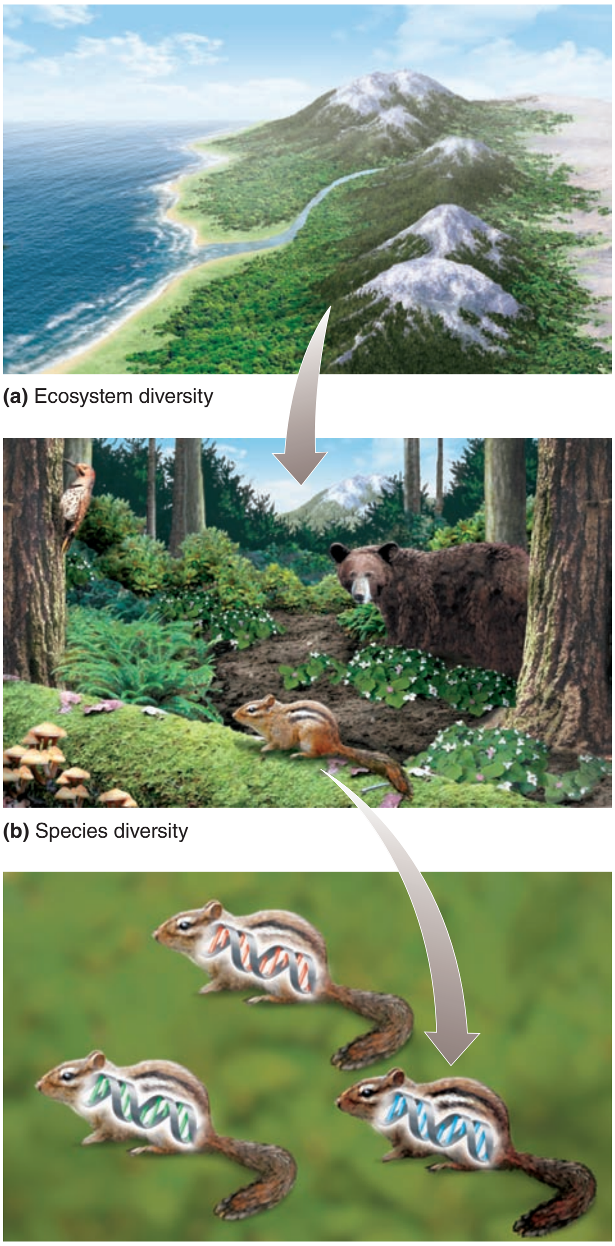
Genetic diversity is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

Species Diversity

A **species** is defined as a group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles.

Species diversity indicates the number of species in a region or in a particular type of habitat. Scientists have observed that ecosystems with more species—that is, higher species diversity—are more productive and resilient—that is, better able to recover from disturbance. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and better able to withstand change, than a nearby tropical forest plantation with one crop species growing in the understory.

Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate environmental problems on a larger scale. Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The



(a) Ecosystem diversity

(b) Species diversity

(c) Genetic diversity

FIGURE 2.1 Levels of biodiversity. Biodiversity exists at three scales. (a) Ecosystem diversity is the variety of ecosystems within a region. (b) Species diversity is the variety of species within an ecosystem. (c) Genetic diversity is the variety of genes among individuals of a species.

Biodiversity The diversity of life forms in an environment.

Genetic diversity A measure of the genetic variation among individuals in a population.

Species A group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties.

Species diversity The number of species in a region or in a particular type of habitat.