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SCIENTIFIC AMERICAN
environmental science
FOR A CHANGING WORLD
SUSAN KARR
JENEEN INTERLANDI
ANNE HOUTMAN
SECOND EDITION

BRIEF CONTENTS

FOOD RESOURCES

CONVENTIONAL ENERGY: FOSSIL FUELS

AIR POLLUTION: CONSEQUENCES OF USING FOSSIL FUELS

ALTERNATIVES TO FOSSIL FUELS

SUSTAINABLE LIVING IN COMMUNITY

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ENVIRONMENTAL SCIENCE

FOR A CHANGING WORLD

SECOND EDITION

SUSAN KARR
Carson-Newman University

JENEEN INTERLANDI
Science Writer

ANNE HOUTMAN
California State University, Bakersfield

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ADDITIONAL CHAPTERS AVAILABLE ONLINE IN LaunchPad

DETAILED CONTENTS

INTRODUCTION TO ENVIRONMENTAL, SCIENCE, AND INFORMATION LITERACY

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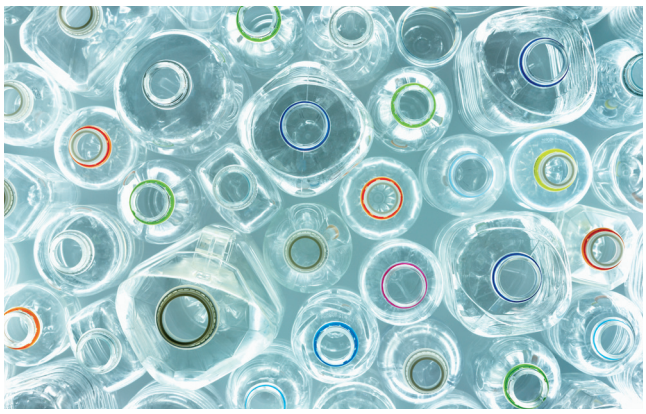

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CONVENTIONAL ENERGY: FOSSIL FUELS

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AVAILABLE ONLINE IN Macmillan Education LaunchPad

http://www.macmillanhighered.com/launchpad/saes2e

ONLINE CHAPTER 26 MINERAL RESOURCES

NO STONE UNTURNED

A bevy of unfamiliar minerals are crucial for our everyday technologies—but they come with a slew of problems

Modern society relies heavily on mineral resources.

INFOGRAPHIC
26.1 Mineral Resources are a Part of Our Everyday Lives
26.2 Earth—A Dynamic Planet

Geologic processes produce mineral resources.

INFOGRAPHIC
26.3 Minerals, Rocks, and the Rock Cycle

Extracting and processing mineral resources impacts the environment.

INFOGRAPHIC
26.4 Mining Techniques
26.5 Extraction of Minerals From Ore Requires Many Processing Steps
26.6 The Environmental Impacts of Mining

Mining also comes with significant social consequences.

INFOGRAPHIC
26.7 The Social Impact of Mining

There are many ways to decrease our use of mineral resources.

INFOGRAPHIC
26.8 Aluminum Recycling: A Success Story
26.9 Alternatives that Reduce Our Use of Mineral Resources

ONLINE CHAPTER 27 SOIL RESOURCES AND GRASSLANDS

RESTORING THE RANGE

The key to recovering the world's grasslands may be a surprising one

Grasslands provide a wide range of important goods and services.

INFOGRAPHIC
27.1 Grasslands of the World
27.2 Grassland Goods and Services

Grasslands face a variety of human and natural threats.

INFOGRAPHIC
27.3 Desertification

The importance of soil can't be overemphasized.

INFOGRAPHIC
27.4 Soil Formation

Grasslands can benefit from the grazing style of wildlife but can be degraded by the grazing practices of modern ranching.

INFOGRAPHIC
27.5 Impacts of wild versus domestic grazers
27.6 Undergrazing can increase the proportion of unpalatable species.

Counteracting overgrazing requires careful planning.

Nature offers clues about how to use grasslands sustainably.

INFOGRAPHIC
27.7 Planned Grazing

There are many ways to protect grasslands.

TABLE
27.1 Protecting Grasslands

ONLINE CHAPTER 28 FORESTS

RETURNING TREES TO HAITI

Repairing a forest ecosystem one tree at a time

The type of forest found in an area reflects local climatic conditions.

INFOGRAPHIC
28.1 Forests of the World
28.2 Cross Section of a Forest

Forests provide a range of goods and services and face a number of threats.

INFOGRAPHIC
28.3 Ecosystem Services of Forests
28.4 Threats to Forests

Forests can be managed to protect or enhance their ecological and economic productivity.

INFOGRAPHIC
28.5 Timber-Harvesting Techniques

When it comes to protecting forests, we have many options.

TABLE
28.1 Protecting Forests

ONLINE CHAPTER 29 MARINE ECOSYSTEMS

ACID OCEANS

Aquanauts explore an ecosystem on the brink

Acidification threatens life in the world's oceans.

INFOGRAPHIC
29.1 pH and Ocean Acidification
29.2 Acidification Alters Ocean Chemistry and Calcification

Marine ecosystems are diverse.

INFOGRAPHIC
29.3 Ocean Life Zones
29.4 Coral reefs: Distribution and Status

ABOUT THE AUTHORS

SUSAN KARR, MS, is an Instructor in the biology department of Carson-Newman University in Jefferson City, Tennessee, and has been teaching for more than 20 years. She has served on campus and community environmental sustainability groups and helps produce an annual "State of the Environment" report on the environmental health of her county. In addition to teaching non-majors courses in environmental science and human biology, she teaches an upper-level course in animal behavior where she and her students train dogs from the local animal shelter in a program that improves the animals' chances of adoption. She received degrees in animal behavior and forestry from the University of Georgia.

Stephen Karr

JENEEN INTERLANDI, MA, MS, is a science writer who contributes to *Scientific American* and *The New York Times Magazine*. Previously, she spent four years as a staff writer for *Newsweek*, where she covered health, science, and the environment. Jeneen has worked as a researcher at both Harvard Medical School and Lamont Doherty Earth Observatory. She was a 2013 Nieman Fellow. In 2014 she received a grant from the Pulitzer Center for Crisis Reporting, to cover the struggles of Roma ascension in Hungary. Jeneen holds Master's degrees in environmental science and journalism, both from Columbia University in New York.

Will Prouty

ANNE HOUTMAN, DPHIL, is Dean of the School of Natural Sciences, Mathematics and Engineering, and Professor of Biological Sciences at California State University, Bakersfield. Her research interests are in the behavioral ecology of birds. She is strongly committed to evidence-based, experiential education and has been an active participant in the national dialogue on science education—how best to teach science to future scientists and future science "consumers"—for almost 20 years. Anne received her doctorate in zoology from the University of Oxford and conducted postdoctoral research at the University of Toronto.

Dear Reader,

For more than 20 years as an environmental science and biology instructor I've found that "stories" capture the imagination of my students. Students are genuinely interested in environmental issues—and using stories to teach these issues makes the science more relevant and meaningful to them. Many leave the class with an understanding that what they do really matters, and they feel a willingness to act on that knowledge. This is why I am enthusiastic about our textbook, *Environmental Science for a Changing World.*

Each chapter will keep students engaged and reading to find out "what happens next." At the same time, explanations of science are woven into the narrative and illustrated in vivid infographics that give additional detail without slowing down the story. We've heard from instructors using the book (and our own students) and we know students are actually reading the textbook and being drawn into the stories, making it is easier for them to make connections between the environmental science concepts being taught and the "bigger picture" of why it matters.

In this book we've broken some topics down into multiple chapters—for instance, we present separate, short chapters on coal, petroleum and natural gas, and nuclear power rather than the traditional single chapter on conventional energy. This gives instructors the flexibility to focus on discrete topics if they choose.

In this second edition, we have added some popular chapters (originally in the extended edition only): Environmental Health, Environmental Policy, World Hunger, and Biodiversity Preservation. We also moved some of the chapters online to LaunchPad, the textbook's web platform, as a way to make all of our chapters available to every adopter, giving even more flexibility in choosing which chapters and topics to cover. (LaunchPad chapters new to the second edition include a chapter on Mineral Resources and Geology as well as an additional agriculture chapter on Raising Livestock in CAFOs. Other chapters found in the first edition that now reside on LaunchPad include chapters on Forest Resources, Grasslands and Soils, Marine Resources, Fisheries, and Biofuels.) Every chapter has been updated to include the latest information.

We also listened to instructor feedback and in this second edition we have added pedagogical aids such as key concepts and end-of-chapter study aids that are tied to the guiding questions that open each chapter. This will help students focus on the important environmental science concepts being presented in the chapter. We've also added questions to each infographic to better engage the student with the figures and diagrams.

As with the first edition, the text focuses on building core competencies for the non-major: environmental literacy, science literacy, and information literacy. End-of-chapter and online exercises provide further opportunities to develop these competencies, as well as critical thinking skills.

Environmental Literacy: The scientific, social, political, and economic facets of contemporary environmental issues are examined with a focus on the scientific concepts and drivers underlying issues. Material is presented in a balanced way, especially for controversial topics. Sustainable solutions are presented.

Science Literacy: Each chapter includes experimental evidence and graphical data representation, and describes the day-to-day work of scientists, giving students many opportunities to evaluate evidence and understand the process of science.

Information Literacy: Students must be able to both find information and assess its quality. We explain how to effectively search for and find scientific information, and how to critically analyze that information.

Every person involved in this book—the writers, illustrators, editors, and fellow instructors—has one sincere objective: to help students become informed citizens who are able to analyze issues, evaluate arguments, discuss solutions, and recognize trade-offs as they make up their own minds about our most pressing environmental challenges.

Sincerely,

Susan Karr

CAPTIVATING STORIES

STUDENTS FOLLOW ONE RIVETING STORY THROUGHOUT THE ENTIRE CHAPTER

FROM THE OPENING PAGE TO THE END-OF CHAPTER QUESTIONS, AND EVERYWHERE IN BETWEEN, EACH CHAPTER FOLLOWS AN ENGAGING REAL STORY THAT ILLUSTRATES AND MOTIVATES CORE SCIENCE CONCEPTS. HERE ARE FOUR OF MANY PLACES IN THIS CHAPTER WHERE THE STORY UNFOLDS.

SEE PAGE 220

Laurel Sutherlin of the Rainforest Action Network went to Sumatra to gauge the impact of the expanding palm oil industry on the island.

SEE PAGES 223, 235, 238 & 242

The orangutan is among the many species being driven to the edge of extinction by the pursuit of palm oil. So much of the Sumatran rain forest land has been laid low that Laurel Sutherlin and his team had to travel overnight and through the morning to reach an untouched section. But once there, they witnessed firsthand its rich biodiversity.

Vier Pfoten/Four Paws/RHOI/Rex Features via AP Images

"Sustainable palm is the key to protecting our biodiversity, and our heritage."
—Raviga Sambanthamurthi.

Virtually all of the forest's inhabitants are facing annihilation. "The remaining populations of endemic Sumatran rhinos are widely considered to be the living dead," says Sutherlin. "Their habitat is too sparse, too fragmented and too disturbed, their numbers too few."

SEE PAGE 233

In 2012, Malaysian geneticist Raviga Sambanthamurthi and her team of researchers discovered the SHELL gene, which is responsible for the most productive palm oil fruit. Farmers now can identify the seeds for this fruit before planting, and produce more oil per hectare.

BENEFITS OF PALM OIL	DISADVANTAGES OF PALM OIL
Palm oil is the preferred dietary replacement for trans fats.	Though probably better than trans fats for one's health, it is still a fat whose consumption should be limited.
Palm oil is already widely used in many products.	The high demand for palm oil in products increases the need for more oil palm plantations.
Palm oil is inexpensive.	If palm oil is priced in a way that reflects its true costs, the prices of goods that contain it will increase.
Oil palm plantations can produce much more oil per acre than can other oil crops.	Oil palm plantations reduce biodiversity and decrease the ability of local ecosystems to provide ecosystem services.
ADDRESSING THE TRADE-OFFS	
Cultivation of oil palms should be done in a way to minimize damage to local ecosystems and biodiversity, leaving some areas uncultivated as refuges for local biodiversity. The most productive palm varieties should be used to increase production per acre.	
Manufacturers should only source palm oil that is certified as sustainably grown, and this information should be readily available to consumers.	
Consumers should reduce their use of palm oil products in general and opt for products that contain certified sustainable palm oil to support companies that use it.	
Consumers should be educated so that they understand that consumption of palm oil (in foods), like consumption of any other fat, must be moderate.	

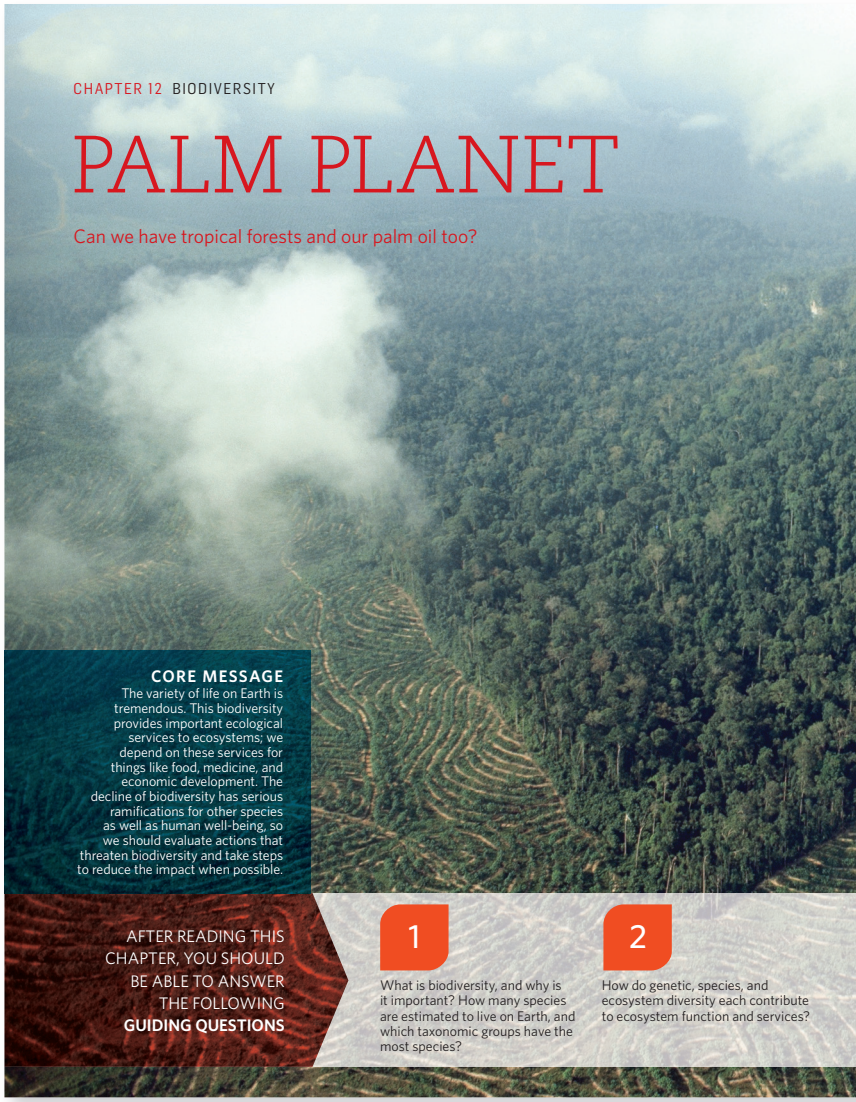
SEE PAGES 244-245

Consumer demands are leading to changes in the palm oil industry. Thanks to the "Snack Food 20" Campaign by Laurel Sutherlin's Rainforest Action Network, some of the world's largest snack food companies have pledged to use only sustainably produced palm oil.

EMPOWERING SCIENCE

ENVIRONMENTAL SCIENCE FOR A CHANGING WORLD OFFERS A CONSISTENT METHODOLOGY FOR TEACHING THE FIELD'S ESSENTIAL SCIENTIFIC CONCEPTS, WITH EACH CHAPTER CENTERED AROUND FIVE GUIDING QUESTIONS.

THESE QUESTIONS ESTABLISH A CLEAR, STEP-BY-STEP PATHWAY THROUGH THE CHAPTER FROM THE OPENING STORY; THROUGH THE NARRATIVE, KEY CONCEPT CALLOUTS, PHOTOS, INFOGRAPHICS; TO THE END-OF-CHAPTER ASSESSMENT. THE QUESTIONS BRING THE SCIENCE IN THE CHAPTER TO THE FOREFRONT, SO STUDENTS NEVER LOSE SIGHT OF FUNDAMENTAL CONCEPTS WHILE READING THE STORY.



CHAPTER 12 BIODIVERSITY

PALM PLANET

Can we have tropical forests and our palm oil too?

CORE MESSAGE
The variety of life on Earth is tremendous. This biodiversity provides important ecological services to ecosystems; we depend on these services for things like food, medicine, and economic development. The decline of biodiversity has serious ramifications for other species as well as human well-being, so we should evaluate actions that threaten biodiversity and take steps to reduce the impact when possible.

AFTER READING THIS CHAPTER, YOU SHOULD BE ABLE TO ANSWER THE FOLLOWING **GUIDING QUESTIONS**

1 What is biodiversity, and why is it important? How many species are estimated to live on Earth, and which taxonomic groups have the most species?

2 How do genetic, species, and ecosystem diversity each contribute to ecosystem function and services?

1

2

Tropical forests tend to be particularly flush with both ecological and species diversity, thanks largely to the abundant sunlight and climatic conditions conducive to growth. The forests that are currently being laid low in Sumatra are no exception. They have been left unhampered for so many millennia that these steamy amphibious ecosystems swarm with a cornucopia of life: elephants, orangutans, tapirs, tigers, and every manner of bird and beetle the human imagination can fathom. "The truth is, no one has any idea how many species used to live here," Sutherlin says. "Half the species in these forests have yet to be described to science."

KEY CONCEPT 12.4

Protecting biodiversity hotspots, areas with high numbers of endangered endemic species, can be a cost-effective way to protect a large number of endangered species.

pg 235

KEY CONCEPT 12.5

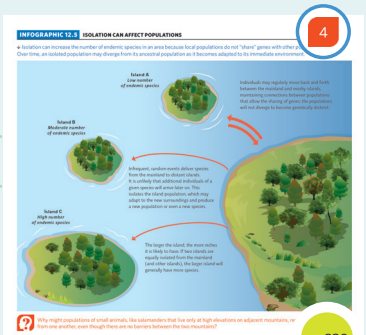
Isolated populations are especially vulnerable to detrimental environmental changes because they cannot freely breed with other populations and thereby increase their genetic diversity and chances of survival.

Endemism increases with isolation, as does extinction risk.

Species come to islands such as Sumatra in various ways: They may be blown in on storms, they may arrive as lost migrators, or the island may have broken off from a larger landmass at some point. Because these are rare events, once a species arrives, it is unlikely to be joined by other members of its species. The founding population is therefore isolated, and as it adapts over time to its new island home, it may eventually evolve into a new species (see Chapter 11 for more on the *founder effect*). For this reason, the number of unique species (the degree of endemism) generally increases with isolation. On the Hawaiian Islands, almost [illegible] (2,400 miles) from the nearest mainland, [illegible] species are endemic.

pg 236

3



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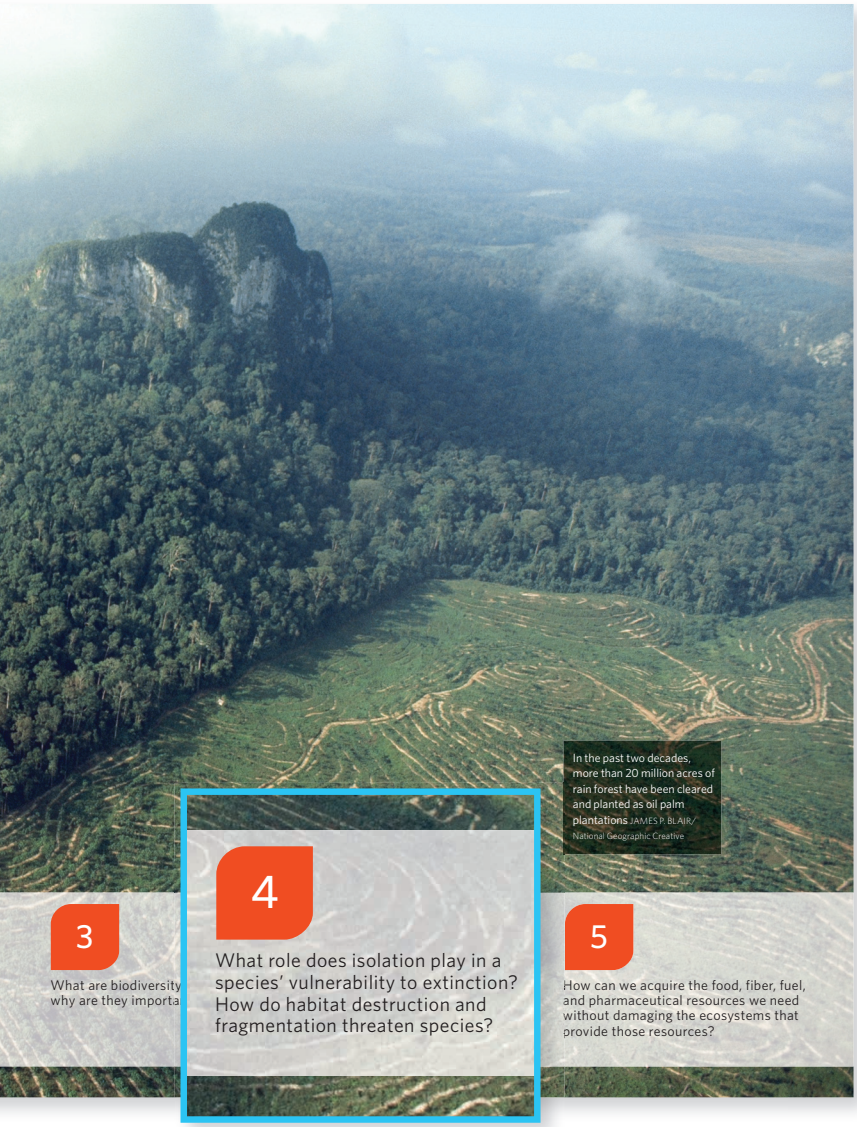
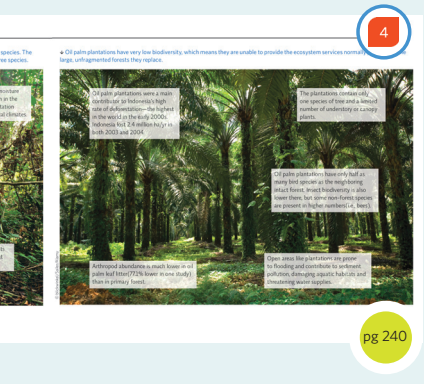


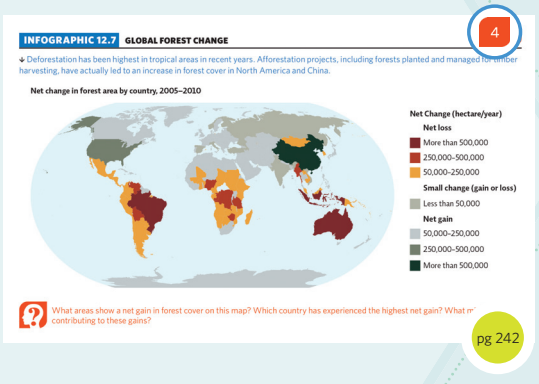
1 Each chapter begins with a Core Message and a series of Guiding Questions that focus students on the chapter's central scientific content.

2 The new Key Concepts correspond to the Guiding Questions, re-emphasizing the chapter's essential scientific ideas.

3 Moving through the chapter, students encounter icons that connect the Guiding Questions to specific sections and infographics, where they'll find the information they need to think critically about the question.

4 Guiding Questions provide the framework for the end-of-chapter pedagogy, which includes references back to relevant infographics to help students answer the questions and prepare for exams.





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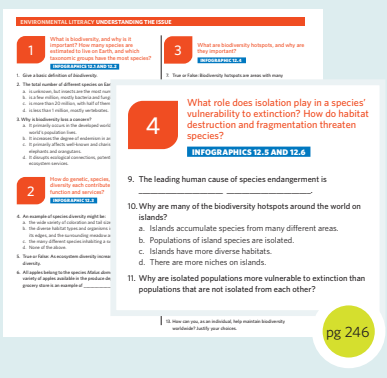


WHAT'S NEW

ONE UNIFIED BOOK THAT COVERS THE MOST ESSENTIAL CONTENT IN THE COURSE

REVISED, LEARNING-FRIENDLY **TABLE OF CONTENTS**

THE MOST CURRENT STORIES IN ENVIRONMENTAL SCIENCE. **BRAND NEW STORIES** IN THIS EDITION:

Dimas Ardian/Bloomberg via Getty Images

CHAPTER 12

In the past two decades, more than 20 million acres of rainforest—primarily in Indonesia—have been cleared and planted as palm oil plantations. **Chapter 12** dives into the Trade-Offs associated with this new, ubiquitous ingredient, and how we might use sustainable practices to keep our palm oil, and rainforests too.

VICTORIA LOE/KRT/Newscom

CHAPTER 15

A patch of the Gulf of Mexico the size of Connecticut is plagued by low-oxygen waters—conditions that threaten wildlife and the local economy. Researchers profiled in **Chapter 15** have been working tirelessly to pinpoint the oxygen-depleting culprit and come up with ways we might help the Gulf breathe again.

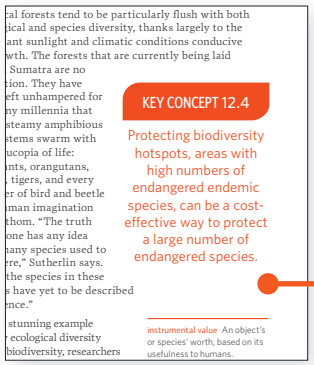
© Jim West/Alamy

CHAPTER 19

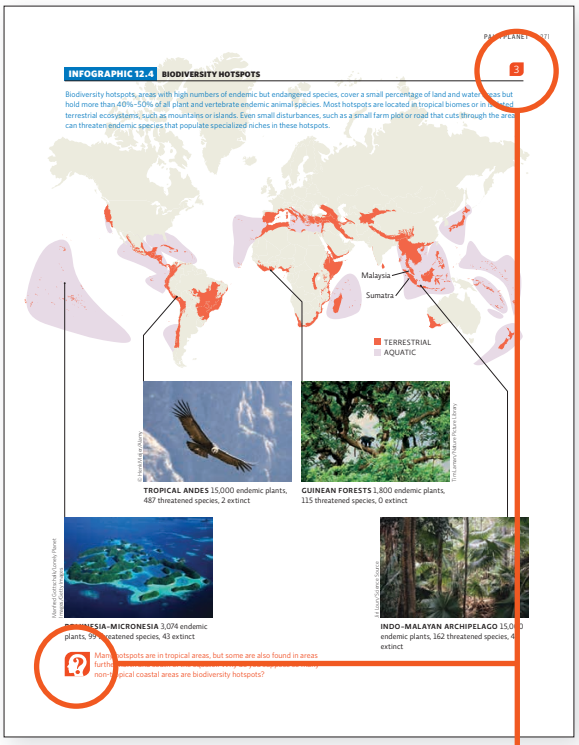
An oil boom is transforming sleepy towns into overcrowded, bustling, urban hubs. To access the oil, the industry is using a new kind of technology called fracking. **Chapter 19** delves into the impacts, both social and environmental, of this new way of harvesting oil.

NEW WAYS OF EMPOWERING SCIENCE LEARNING

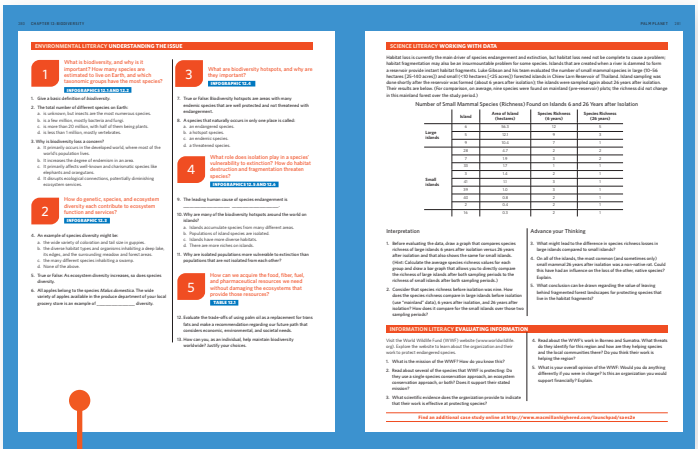
A **LEARNING PATH** AT THE BEGINNING OF EACH CHAPTER HOMES STUDENT ATTENTION TO THE CORE MESSAGE AND GUIDING QUESTIONS.



KEY CONCEPTS ALERT STUDENTS TO SALIENT TAKE-HOME MESSAGES WITHIN THE CHAPTER TEXT AND ENFORCE THE GUIDING QUESTIONS.



EACH **INFOGRAPHIC IS TAGGED** TO A GUIDING QUESTION—THE CONTENT IN THE FIGURE HELPS STUDENTS ANSWER THE QUESTION. NEW **CRITICAL THINKING QUESTIONS** HAVE BEEN ADDED TO EACH FIGURE IN THE BOOK.



NEW PRACTICE QUESTIONS IN THE END-OF-CHAPTER MATERIAL TEACH EACH GUIDING QUESTION.

RESOURCES TARGET THE MOST CHALLENGING CONCEPTS AND SKILLS IN THE COURSE

Classroom activities, animations, tutorials, and assessment materials are all built around the concepts and skills that are most difficult for students to master

INSTRUCTOR RESOURCES

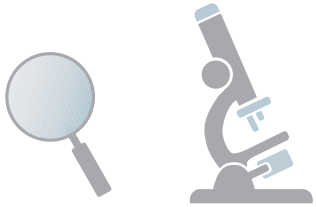
Macmillan Education LaunchPad

LaunchPad A new standard in online course management, LaunchPad makes it easier than ever to create interactive assignments, track online homework, and access a wealth of extraordinary teaching and learning tools. Fully loaded with our customizable e-Book and all student and instructor resources, the LaunchPad is organized around a series of prebuilt LaunchPad units—carefully curated, ready-to-use collections of material for each chapter of *Environmental Science for a Changing World.*

***Scientific American* newsfeed** Available on the LaunchPad welcome page, the *Scientific American* newsfeed allows you and your students to access current and relevant content from *Scientific American*. You can also choose to assign the articles or bookmark them for later.

LECTURE TOOLS

Optimized Art (JPEGs and layered PowerPoint slides) Infographics are optimized for projection in large lecture halls and split apart for effective presentation.



Layered or Active PowerPoint Slides PowerPoint slides for select figures deconstruct key concepts, sequences, and processes in a step-by-step format, allowing instructors to present complex ideas in clear, manageable parts.

Lecture Outlines for PowerPoint Adjunct professors and instructors who are new to the discipline will appreciate these detailed companion lectures, perfect for walking students through the key ideas in each chapter. These rich, prebuilt lectures make it easy for instructors to transition to the book.

Team-Based Learning Activities Developed by author Susan Karr, these classroom activities use proven active-learning techniques to engage students in the material and inspire critical thinking. These activities are intended for an instructor who is interested in taking an active learning approach to the course.

Clicker Questions Designed as interactive in-class exercises, these questions reinforce core concepts and uncover misconceptions.

Story Abstracts The abstracts offer a brief story synopsis, providing interesting details relevant to the chapter and to the online resources not found in the book.

ASSESSMENT

Macmillan Education LearningCurve

Learning Curve A game-like interface to guide students through a series of questions tailored to their individual level of understanding.

Videos A new suite of videos for the 2nd edition, including videos on Biodiversity, Climate Change, Human Populations, Energy (including Fracking), and more. Videos bring the stories of environmental science to life and make the materials meaningful to students. Each video is assignable and includes assessment questions to gauge student understanding.

Test Bank A collection of over a thousand questions, organized by chapter and Guiding Question, presented in a sortable, searchable platform. The Test Bank features multiple-choice and short-answer questions, and uses infographics and graphs from the book.

Post-Chapter Quizzes Post-Chapter quizzes are brief 5-10 question quizzes that test the students' basic knowledge of the chapter. They are aligned to the new 2nd edition chapters and Guiding Questions.

Course Management System e-packs available for Blackboard, WebCT, and other course management platforms.

ORGANIZED BY GUIDING QUESTIONS

Student and instructor resources are arranged to support the learning goals of each chapter

SUPPORT ENVIRONMENTAL, SCIENCE, AND INFORMATION LITERACY

Supplementary materials explore timely environmental issues, develop crucial science literacy skills such as data analysis and graph interpretation, and provide practice in evaluating sources of information

STUDENT RESOURCES

Student resources reinforce chapter concepts and give students the tools they need to succeed in the course. All student resources are organized by Guiding Questions and can be found in the LaunchPad.

Macmillan Education LaunchPad

LaunchPad Students have access to a variety of study tools in the LaunchPad along with a complete online version of the textbook. Carefully curated LaunchPad Units provide suggested learning paths for each chapter in the text.

Macmillan Education LearningCurve

Learning Curve This set of formative assessment activities uses a game-like interface to guide students through a series of questions tailored to their individual level of understanding. A personalized study plan is generated based upon their quiz results. LearningCurve is available to students in the LaunchPad.

GraphingTutorials let students build and analyze graphs, using their critical thinking skills to predict trends, identify bias, and make cause-and-effect connections.

Video Case Studies Videos from an array of trusted sources bring the stories of the book to life and allow students to apply their environmental, scientific, and information literacy skills. Each video includes questions that engage students in the critical thinking process.

Interactive Animated Infographics Most infographics in the text include an animated interactive tutorial or an infographic activity.

Key Term Flashcards Students can drill and learn the most important terms in each chapter using interactive flashcards.

Lecture Art Notebook The infographics for each chapter are available as PDF files that students can download and print before lectures.

ACKNOWLEDGEMENTS

From Susan Karr...

I've discovered that an undertaking this big is truly a collaborative effort. It is amazing what you can accomplish when you work with talented and highly skilled people. I want to thank Jerry Correa for his original vision for the book and personal support and W. H. Freeman acquisitions editor Bill Minick for his continued support and guidance; and developmental editor Andrea Gawrylewski for her patience, insights, and outstanding editorial skills in crafting each chapter. I also want to thank Jeneen Interlandi, the accomplished and gifted writer who has made these chapters such a pleasure to read. Outstanding writing was also done by Alison McCook and Melinda Wenner Moyer. I gratefully acknowledge the entire team at MGMT. design for their skills, vision, and patience, and the folks at Cenveo who expertly coordinated the production of the book. Thanks also go to John Britch, the executive marketing manager, and the sales force, who work tirelessly to see that the book is a success in the marketplace

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From Jeneen Interlandi...

Each of these chapters is a story—of scientists and everyday people, often doing extraordinary things. It has been my great pleasure to tell those stories here. For that, I thank each and every one of my sources. Their time and patience are what made this book possible.

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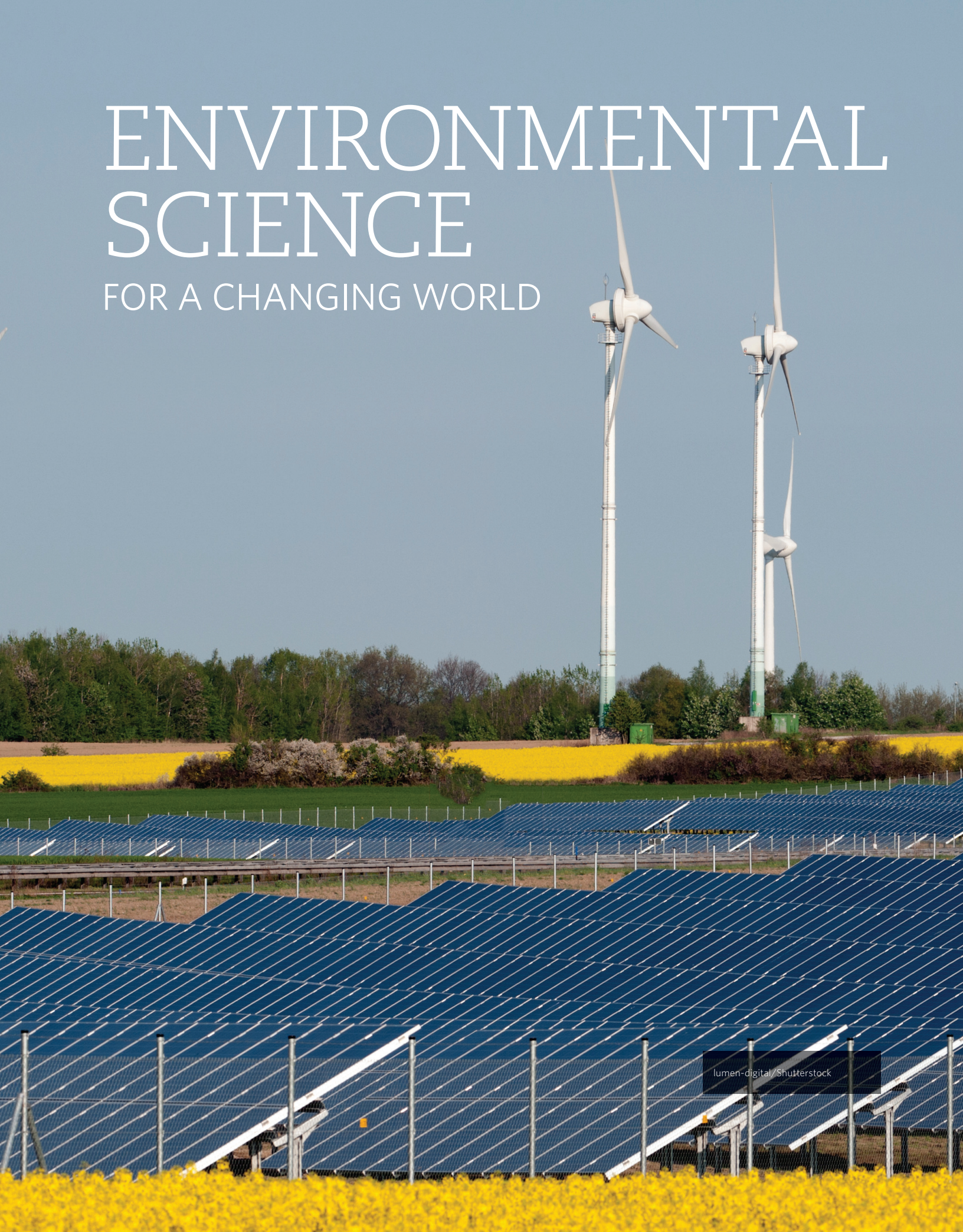
ENVIRONMENTAL SCIENCE

FOR A CHANGING WORLD



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ON THE ROAD TO COLLAPSE

What lessons can we learn from a vanished Viking society?

CORE MESSAGE

Humans are a part of the natural world and are dependent on a healthy, functioning planet. We put pressure on the planet in a variety of ways, but our choices can help us move toward sustainability.

AFTER READING THIS CHAPTER, YOU SHOULD BE ABLE TO ANSWER THE FOLLOWING **GUIDING QUESTIONS**

1. What constitutes the "environment," and what fields of study collaborate under the umbrella of environmental science?

2. What are some of the environmental dilemmas that humans face, and why are many of them considered "wicked problems"?

The remains of Hvalsey, a Viking settlement church, in southern Greenland.
Paul Souders/WorldFoto/Aurora Photos

3

What does it mean to be sustainable, and what are the characteristics of a sustainable ecosystem?

4

What can human societies and individuals do to pursue sustainability?

5

What challenges does humanity face in dealing with environmental issues, and how can environmental literacy help us make more informed decisions?

Although not much of a tourist destination, Greenland offers some spectacular sights—colossal ice sheets, a lively seascape, rare and precious wildlife (whales, seals, polar bears, eagles). But on his umpteenth trip to the island, Thomas McGovern was not interested in any of that. What he wanted to see was the garbage—specifically, the ancient, fossilized garbage that Viking settlers had left behind some seven centuries before.

McGovern, an archaeologist at the City University of New York, had been on countless expeditions to Greenland over the preceding 40 years. Digging through layers of peat and permafrost, he and his team had unearthed a museum's worth of artifacts that, when pieced together, told the story of the Greenland Vikings. But as thorough as their expeditions had been, that story was still maddeningly incomplete.

KEY CONCEPT 1.1

Environmental science draws from science and non-science disciplines to understand and address environmental problems.

Here's what they knew so far: A thousand or so years ago, an infamous Viking by the name of Erik the Red led a small group of followers across the ocean from Norway, to a vast expanse of snow and ice that he had dubbed Greenland. Most of Greenland was not green. In fact, it was a forbidding place marked by harsh winds and sparse vegetation. But tucked between two fjords along the southwestern coast, protected from the elements by jagged, imposing cliffs, the Vikings found a string of verdant meadows, brimming with wildflowers. They quickly set up camp here and proceeded to build a society similar to the one they had left behind in Norway. They farmed, hunted, and raised livestock. They also built barns and churches as elaborate as the ones back home. They established an economy and a legal system, traded goods with mainland Europe, and, at their peak, reached a population of 5,000 (a large number in those days).

And then, after 450 years of prosperity, they disappeared—seemingly into thin air—leaving little more than the beautiful, tragic ruins of a handful of barns and churches in their wake.

The how and why of this vanishing act remained a tantalizing mystery, one that has drawn hundreds of scientists—McGovern among them—to Greenland each summer. Recently, some of McGovern's colleagues had begun to suspect that disturbances in the natural environment—a cooling climate, loss of soil, problems with the food supply—may have been the deciding factors.

While other researchers probed ice sheets and soil deposits in search of clues, McGovern stuck to the garbage heaps, or *middens*, as Vikings called them. Every farmstead had one, and every generation of the farmstead's owners threw their waste into it. The result was an archaeological treasure trove: fine-grain details about what people ate, how they dressed, and the kinds of objects they filled their homes with. It gave McGovern and his team a clear picture of how they lived.

If they dug deep enough, McGovern thought, it might also explain how they died.

Environmental science is all encompassing.

From a modern developed society like the United States, it can be difficult to imagine a time and place when the natural world held such sway over our fate.

WHERE IS THE VIKING SETTLEMENT IN GREENLAND?

PETE RYAN/National Geographic Creative

Our food comes from a grocery store, our water from a tap; even our air is artificially heated and cooled to our liking. These days, it seems more logical to consider societal conflict, or even collapse, through the lens of politics or economics. But, as we will see time and again throughout this book, the natural environment—and how we interact with it—plays a leading role in the sagas that shape human history; this is as true today as it was in the time of the Vikings.

Environment is a broad term that describes the surroundings or conditions (including living and nonliving components) in which any given organism exists. **Environmental science**—a field of research that is used to understand the natural world and our relationship to it—is extremely interdisciplinary. It relies on a range of natural and applied sciences (such as ecology, geology, chemistry, and engineering) to unlock the myster of the natural world, and to look at the role and impact of humans in the world. It also draws on social sciences (such as anthropology, psychology, and economics) and the humanities (such as art, literature, and music) to understand the ways that humans interact with, and thus impact, the ecosystems around them. **INFOGRAPHIC 1.1**

environment The biological and physical surroundings in which any given living organism exists.

environmental science An interdisciplinary field of research that draws on the natural and social sciences and the humanities in order to understand the natural world and our relationship to it.

Environmental science is an **empirical science**: It scientifically investigates the natural world through systematic observation and experimentation. It is also an **applied science**: We use its findings to inform our actions and, in the best cases, to bring about positive change. **INFOGRAPHIC 1.2**

The ability to understand environmental problems is referred to as **environmental literacy**. Such literacy is crucial to helping us become better stewards of Earth. Environmental problems can be extremely complicated and tend to have multiple causes, each one difficult to address. We must also understand that because of their complexity, any given response to an environmental problem involves significant **trade-offs**, and no one response is likely to present the ultimate solution. Scientists refer to such problems as "wicked problems." In confronting them, we must consider not only their environmental but also their economic and social causes and consequences. Scientists refer to this trifecta as the **triple bottom line**. **INFOGRAPHIC 1.3**

KEY CONCEPT 1.2

Environmental problems are difficult to solve because there are multiple causes and consequences and because potential solutions come with trade-offs.

In his book *Collapse*, University of California at Los Angeles biologist Jared Diamond details how wicked problems can lead to a society's ultimate demise. He identifies five factors in particular that determine whether any given society will succeed or fail: natural climate change, failure to properly respond to environmental changes, self-inflicted environmental damage, hostile neighbors, and loss of friendly neighbors. According to Diamond, the relative impact of each factor varies by society.

The situation of the Greenland Vikings was a rare case. It turns out that, as in a perfect storm, all five of these factors conspired together.

The Greenland Vikings' demise was caused by natural events and human choices.

Greenland's interior is covered by vast ice sheets that stretch toward the horizon—3,000 meters (10,000 feet) thick and more than 250,000 years old. To residents of the hard land, these ice sheets are not good for much—they create harsh winds and brutal cold—but to climate

INFOGRAPHIC 1.2 DIFFERENT APPROACHES TO SCIENCE HAVE DIFFERENT GOALS AND OUTCOMES 1

Environmental science is used to systematically collect and analyze data to draw conclusions and use these conclusions to propose reasonable courses of action.

EMPIRICAL SCIENCE IS USED TO INVESTIGATE THE NATURAL WORLD

Ashley Cooper/GHG/Aurora Photos

↑ Through observation, glaciologists study and record the rate of glacier melt in Greenland; it is increasing dramatically in some far flung places.

IN APPLIED SCIENCE, KNOWLEDGE IS USED TO ADDRESS PROBLEMS OR NEEDS

Verkis Consulting Engineers

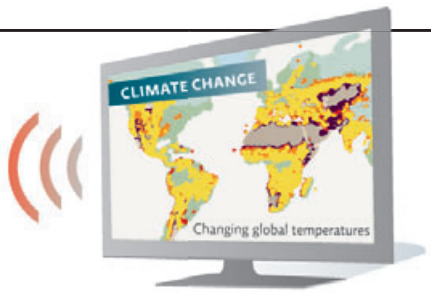
↑ Engineers use their understanding of flowing water's potential energy to harness its power; glacial meltwater can be diverted to produce hydroelectric power.

If we don't have an application in mind for an empirical research topic, is it worth pursuing?

2

INFOGRAPHIC 1.3 WICKED PROBLEMS

Wicked problems are difficult to address because, in many cases, each stakeholder hopes for a different solution. Solutions that address wicked problems usually involve trade-offs, so there is no clear "winner." One example of a wicked problem is climate change. There are many causes of the current climate change we are experiencing, both natural and anthropogenic (caused by human actions), and the effects of climate change will be varied for different species and people, depending on where they live and their ability to adapt to the changes.



CLIMATE CHANGE

SOME OF THE CAUSES:

- Burning fossil fuels
- Deforestation
- Methane from agriculture
- Overconsumption by modern society

SOME OF THE CONSEQUENCES:

- Sea level rise
- Habitat loss and species endangerment
- Spread of tropical disease
- Agriculture: worse in some areas, better in others

POSSIBLE ACTIONS (AND POTENTIAL TRADE-OFFS) INCLUDE:

- Alternative energy sources (less pollution but can be costly)
- Irrigation (increases crop yields but can cause water shortages and soil problems)
- Reforestation projects (lessen CO_2 in atmosphere and increase habitats but may take land needed for agriculture or other uses)
- Protecting flood-prone areas with levees or sea walls (may protect cities and farms but may fragment aquatic habitats and isolate species' populations)

What are some other environmental "wicked problems" we face?

scientists, they're a treasure trove. As snow falls, it absorbs various particles from the atmosphere and lands on the ice sheets. As time passes, the snow and particles compact into ice, freezing in time perfect samples of the atmosphere as it existed when that snow first fell. By analyzing those ice-trapped particles—dust, gases, chemicals, even the water molecules—scientists can get a pretty good idea of what was happening to the climate at any given time. "It's like perfectly preserved slices of atmosphere from the past," says Lisa Barlow, a geologist and climate researcher at the University of Colorado at Boulder. "It gives us additional clues as to what was going on."

To uncover those clues, a team of scientists and engineers picked an accessible segment of ice sheet, not far from the Viking settlements, drilled from the surface all the way down to the bedrock below, and extracted a 12-centimeter-wide (5-inch-wide), 3,000-meter-long cylinder of ice, which they then divided and dispersed among a handful of labs around the globe, including Jim White's light stable isotope lab—also at the University of Colorado at Boulder. Analysis of thin sequential segments of the ice core showed that when the Vikings first arrived in Greenland, the temperature was anomalously higher than the average over the preceding 1,000 years. (Atmospheric temperature can be deduced from the amount of oxygen-18 or deuterium—heavy hydrogen—present in the sample.) By the time the Vikings had vanished, temperatures had lowered so

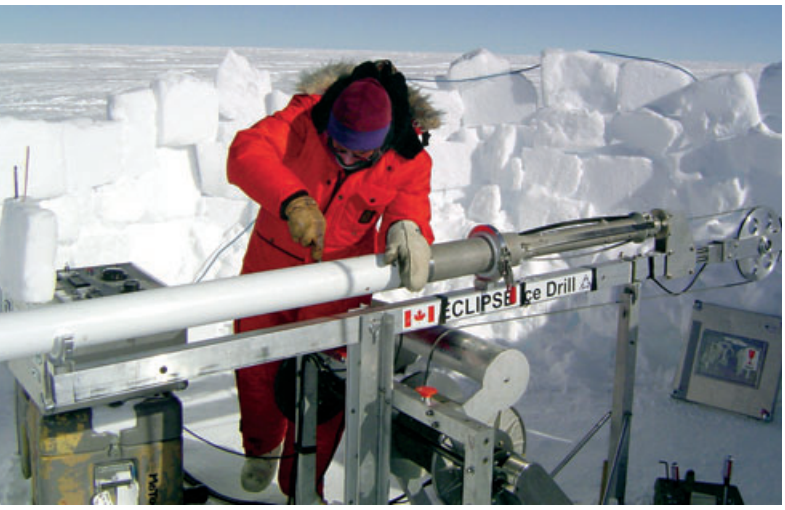
empirical science A scientific approach that investigates the natural world through systematic observation and experimentation.

applied science Research whose findings are used to help solve practical problems.

environmental literacy A basic understanding of how ecosystems function and of the impact of our choices on the environment.

trade-offs The imperfect and sometimes problematic responses that we must at times choose between when addressing complex problems.

triple bottom line The combination of the environmental, social, and economic impacts of our choices.



NSIDC courtesy Ted Scambos and Rob Bauer.

↑ Scientist from the National Snow and Ice Data Center at the University of Colorado at Boulder, working with an ice core drill.

much that scientists call the period the Little Ice Age—a time when all the seasons were cooler than normal and winters were exceptionally cold. "It's no wonder they didn't make it," says Barlow. "With lower temperatures, livestock would have starved for lack of hay over the long winter, and self-inflicted environmental damage made the situation worse."

Indeed, in addition to natural climate change (Diamond's first factor), the Vikings also suffered from self-inflicted environmental damage (Diamond's second factor).

In addition to that single ice core, scientists have analyzed hundreds of mud cores taken from lake beds around the Viking settlements. These mud samples—which contain large amounts of soil that was blown into the lakes during Viking times—indicate that soil erosion had become a significant problem long before the region descended into a mini ice age. "This wasn't a climate problem," says Bent Fredskild, a Danish scientist who extracted and studied many of the mud cores. "This was self-inflicted. It happened the same way that soil erosion happens today—they overgrazed the land, and once it was denuded, there was nothing to anchor the soil in place. So the wind carried it away."

Overgrazing wasn't their only mistake. The Greenland Vikings also used grassland to insulate their houses against the cold of winter; typical insulation consisted of 2-meter-thick (about 6 feet) slabs of turf, and a typical home took about 4 hectares (10 acres) of grassland to insulate. On top of that, they chopped down the forests, harvesting enough timber to not only provide fuel and build houses but also to make the innumerable wooden objects to which they had become accustomed back in Norway.

Greenland's ecosystem was far too fragile to endure such pressure, especially as the settlement grew from a few hundred to a few thousand. The short, cool growing season meant that plants developed slowly, which in turn meant that the land could not recover quickly enough from the various assaults to protect the soil.

As climate cooling and overharvesting conspired to destroy pasturelands, summer hay yields shrank. When scientists counted the fossilized remains of insects that lived in the fields and haylofts of Viking Greenland, they found that their numbers fell dramatically in the settlement's final years. "The falloff in insects tells us that hay production dwindled to the point of crisis," said the late Peter Skidmore, a Sheffield University entomologist. Without hay, livestock could not survive the ever-colder, ever-longer winters. And without livestock, the Vikings themselves went hungry. As scientists have discovered, they needn't have.

Responding to environmental problems and working with neighbors help a society cope with changes.

Back in his Manhattan lab, McGovern sorts through hundreds of animal bones collected from various Greenland middens. By examining the bones and making careful note of which layers they were retrieved from, McGovern can tell what the people ate and how their diets changed over time. "This is a pretty typical set of remains for these people from this region and time period," he says, leaning over a shiny metal tray of neatly arranged bone fragments. Some are the bones of cattle imported from Europe. Others are the remains of sheep and goats; still others of local wildlife such as caribou. Conspicuously absent, McGovern says, are fish of any kind.

"If we look at a comparable pile of bones from [Norwegian settlers of] the same time period, from Iceland, we see something very different," McGovern explains. "We have fish bones and bird bones and little fragments of whale bones. Most of it, in fact, is fish—including a lot of cod." It turns out that while the Greenland Vikings were guilty of Diamond's third factor, failure to respond to the natural environment, their Icelandic cousins were not.

Like their cousins in Greenland, the Vikings who settled Iceland at about the same time were initially fooled into thinking that their newly discovered land could sustain their cow-farming, wood-dependent ways: Plants and animals looked similar to those back in Norway, and grasslands seemed lush and abundant. They cleared about 80% of Iceland's forests and allowed their cows, sheep,

KEY CONCEPT 1.3

Living sustainably means living within the means of one's environment in a way that does not diminish the environment's ability to support life in the future.

and goats to chew the region's grasslands down to nothing before finally noticing how profound the differences between Iceland and Norway actually were: Growing seasons in Iceland were shorter, both soil and vegetation were much more fragile, and because the land could not rebound quickly, cow farming was unsustainable.

But once they saw that their old ways would not work in this new country, the Icelandic Vikings made changes. Not only did they switch from beef to fish, they also began conserving their wood and abandoned the highlands, where soil was especially fragile. And, as a result of these and other adaptations, they survived and prospered. The Icelanders responded to the limitations of their natural environment in a way that allowed them to meet present needs without compromising the ability of future generations to do the same—an approach known today as **sustainable development**.

Some of the most telling clues to the mystery of the Greenland Vikings' demise come not from the Viking colonies but from another group of people who lived nearby: the Inuit. The Inuit arrived in the Arctic centuries before the Vikings. They were expert hunters of ringed seal—an exceedingly difficult-to-catch but very abundant food source. They knew how to heat and light their homes with seal blubber (instead of firewood). And they were experts at fishing.

Fishing is not nearly as labor intensive as raising cattle, and in the lakes and fjords of Greenland, it provides an easy, reliable source of protein. A comparison of Inuit and Viking middens shows that even as the Greenland Vikings were scraping off every last bit of meat and marrow from their cattle bones, the Inuit had more food than they could eat.

The Vikings might have learned from their Inuit neighbors; by adapting some of their customs, they might have survived the Little Ice Age and gone on to prosper as the Icelandic Vikings did. But excavations show that virtually no Inuit artifacts made their way into Viking settlements. And according to written records, the Norse detested the Inuit, who, on at least one occasion, attacked the Greenland colony; they called the Inuit *skraelings*, which is Norse for "wretches," considered them inferior, and refused to seek their friendship or their counsel.

In addition to these hostile neighbors (Diamond's fourth factor), the Greenland Vikings also suffered a loss of friendly neighbors (Diamond's fifth factor). As the productivity of the Viking colonies declined, so did visits from European ships. As time wore on, it became apparent that the Greenland Vikings could expect very little in the way of trade; royal and private ships that had visited every year came less and less often. After a while, they did not come at all. For the Greenland Vikings, who depended on the Europeans for iron, timber, and other essential supplies, this loss proved devastating. Among other things, it meant that, as the weather grew colder, and food supplies dwindled, they had no one to turn to for help.

Humans are an environmental force that impacts Earth's ecosystems.

When it comes to the environment, modern societies are not as different from the Vikings as one might assume. Vikings chose livestock and farming methods that were ill suited to Greenland's climate and natural environment. We, too, use farming practices that strip away topsoil and diminish the land's fertility. We have overharvested our forests and in so doing have triggered a cascade of environmental consequences: loss of vital habitat and biodiversity, soil erosion, and water pollution. We have overfished and overhunted and have allowed invasive species to devastate some of our most valuable ecosystems.

KEY CONCEPT 1.4

Modern humans inflict tremendous environmental impact by virtue of our sheer numbers and the high per-person impact of some societies.

In part, these problems stem from a disconnect in our understanding of the relationship between our actions and their environmental consequences. For example, unless they live close by, many people in the United States don't realize that entire mountains are being leveled to produce their electricity; thousands of acres of habitat and miles of streams and rivers have been destroyed to access coal seams deep beneath the surface of West Virginia and Wyoming. We are slow to make the connection between the burning of that coal and mercury-contaminated fish or increased asthma rates.

We also face a suite of new problems that did not trouble the Vikings. Chief among them

sustainable development
Development that meets present needs without compromising the ability of future generations to do the same.