THIRD CANADIAN EDITION

environment

THE SCIENCE BEHIND THE STORIES

jay withgott matthew laposata barbara murck

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UNIVERSITY OF TORONTO MISSISSAUGA

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10 9 8 7 6 5 4 3 2 1 V0H0

Library and Archives Canada Cataloguing in Publication

Withgott, Jay, author
Environment : the science behind the stories / Jay Withgott, Matthew Laposata (Kennesaw State University (KSU)), Barbara Murck (University of Toronto). -- Third Canadian edition.

Includes bibliographical references and index.
ISBN 978-0-321-93146-7 (paperback)

1. Environmental sciences--Textbooks. I. Laposata, Matthew, author II. Murck, Barbara W. (Barbara Winifred), 1954-, author III. Title.

GE105.W58 2016 363.7 C2015-904095-7

PEARSON

ISBN 978-0-321-93146-7

Brief Contents

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Preface

Dear Student,

You are coming of age at a unique and momentous time in history. Within your lifetime, our global society must chart a promising course for a sustainable future. The stakes could not be higher.

Today we live long lives enriched with astonishing technologies, in societies more free, just, and equal than ever before. We enjoy wealth on a scale our ancestors could hardly have dreamed of. Yet we have purchased these wonderful things at a price. By exploiting Earth's resources and ecological services, we are depleting our planet's bank account and running up its credit card. We are altering our planet's land, air, water, nutrient cycles, biodiversity, and climate at dizzying speeds. More than ever before, the future of our society rests with how we treat the world around us.

Your future is being shaped by the phenomena you will learn about in your environmental science course. Environmental science gives us a big-picture understanding of the world and our place within it. Environmental science also offers hope and solutions, revealing ways to address the problems we create. Environmental science is not simply some subject you learn in college or university. Rather, it provides you basic literacy in the foremost issues of the twenty-first century, and it relates to everything around you over your entire lifetime.

We have written this book because today's students will shape tomorrow's world. At this unique moment in history, students of your generation are key to achieving a sustainable future for our civilization. The many environmental challenges that face us can seem overwhelming, but you should feel encouraged and motivated. Remember that each dilemma is also an opportunity. For every problem that human carelessness has created, human ingenuity can devise a solution. Now is the time for innovation, creativity, and the fresh perspectives that a new generation can offer. Your own ideas and energy *will* make a difference.

Environmental science helps show us how Earth's systems function and how we influence these systems. It gives us a big-picture understanding of the world and our place within it. Studying environmental science helps us comprehend the problems we create, and it can help us find solutions for those problems. This is not just another course in your university or college program; it relates to everything that is around you, and it will resonate for the rest of your life.

Dear Instructor,

You perform one of our society's most vital jobs by educating today's students—the citizens and leaders of tomorrow—on the fundamentals of the world around them, the nature of science, and the most central issues of our time. We have written this book to assist you in this endeavour because we feel that the crucial role of environmental science in today's world makes it imperative to engage, educate, and inspire a broad audience of students.

In *Environment: The Science behind the Stories*, we strive to implement a diversity of modern teaching approaches and to show how science can inform efforts to bring about a sustainable society. We aim to encourage critical thinking and to maintain a balanced approach as we flesh out the vibrant social debate that accompanies environmental issues. As we assess the challenges facing our civilization and our planet, we focus on providing forward-looking solutions, for we truly feel there are many reasons for optimism.

In crafting this latest Canadian edition, we have incorporated the most current information from this fast-moving field of environmental science, and have streamlined our presentation considerably to promote learning. We have examined every line with care to make sure all content is accurate, clear, and as up to date as possible. We also have introduced a number of changes and new material that we think you will enjoy using in your teaching.

We sincerely hope that our efforts will come close to being worthy of the immense importance of our subject matter. We invite you to let us know how well we have achieved our goals and where you feel we have fallen short. We are committed to continual improvement and value your feedback, as does the team at Pearson Canada. Please feel free to write and send comments or suggestions to Barbara Murck at barbara.murck@utoronto.ca.

—Jay Withgott,
Matthew Laposata, and Barbara Murck

The Canadian Edition

When we embarked upon writing a first Canadian edition of *Environment: The Science behind the Stories*, we endeavoured to produce a book that represented a truly Canadian perspective of environmental science, while maintaining the powerful teaching and learning tools of the American edition. We wanted to tell students about the great, sometimes groundbreaking, work done by Canadian environmental scientists. We wanted to celebrate our environmental achievements and history, and familiarize students with the people, locations, and events of that history with examples from coast to coast to coast.

During these years of the Canadian first and second editions, we have enjoyed receiving feedback and suggestions from adopters and reviewers across Canada. You, our users, have told us that you appreciate the truly Canadian focus of the book, as well as the balanced approach and the integration of science with policy. You like the rigour and the breadth and depth of coverage and value our efforts to represent environmental issues from all corners of this vast country and around the world. You also welcome the clarity and liveliness of the writing and the visual program.

We hope you will find that these traditions have continued in the third Canadian edition. We have tackled some of the significant changes that have been happening in Canada, in the physical and biological environment, as well as changes in the political, social, and economic context of our nation that have an impact on the environment. We believe that we have approached these important changes with balance, and a spirit of scientific inquiry.

What's New in the Third Canadian Edition?

For the third Canadian edition we maintain all of the aforementioned strengths, while enhancing the Canadian content, clarifying the overall structure, adding significantly to the cited scientific sources, and updating the book as a whole. We have responded to your suggestions for new examples, additions, and, where needed, conceptual reorganization, and we thank all of the adopters and reviewers who contributed ideas and suggestions.

This has been a deep revision. Some chapters have been streamlined, updated, and strengthened with the addition of new topics; other chapters have been completely restructured. You will now find that the learning objectives in each chapter closely parallel the structure of the chapter headings. In this edition you will also discover scores of new and updated graphs, photographs, and tables, as well as expanded and improved discussions of many topics, new case studies, and scientific focus articles.

Integrated Central Cases

Telling compelling stories about real people and real places is the best way to capture students' interest. Narratives with concrete detail also help teach abstract concepts because they give students a tangible framework with which to incorporate new ideas. We integrate each chapter's "Central Case" into the main text, weaving information throughout the chapter. In this way, the concrete realities of the people and places of the central case study demonstrate the topics we cover. Students and instructors using the book have lauded this approach, and we hope it can continue to bring about a new level of effectiveness in environmental science education. As instructors ourselves, we find the central cases to be extremely effective as a pedagogical tool for opening our lectures and setting the stage for new areas of inquiry.

In the third Canadian edition, 15 of the 22 Central Cases have a specifically Canadian focus. All of the Central Cases have been updated and improved, with additional scientific sources. Four of them are new:

- **Chapter 2:** The Tōhoku Earthquake: Shaking Japan's Trust in Nuclear Power
- **Chapter 13:** "Airpocalypse" in Beijing
- **Chapter 19:** Microplastics: Big Concerns about Tiny Particles
- **Chapter 21:** SARA and the Sage-Grouse

These, along with classic Canadian cases like "Battling over the Last Big Trees at Clayoquot Sound," "Lessons Learned: The Collapse of the Cod Fisheries," and "The Retreat of the Athabasca" tell the important stories—the iconic stories that our students *need* to know if we are to move forward in our search for environmental solutions, rather than repeating the mistakes of the past.

DATA Q Each chapter now contains questions that are specifically aimed at helping students actively engage with graphs and data. The questions accompany some of the data-driven figures in each chapter, challenging students to practise quantitative skills of interpretation and analysis. To encourage students to test their understanding as they read, answers are provided in Appendix A.

The Science behind the Story

Our goal is not simply to present students with facts, but to engage them in the scientific process of testing and discovery. To do this, we feature "The Science behind the Story" boxes, which expand upon particular studies, guiding readers through details of the research. In this way we show not merely what scientists discovered, but *how* they discovered it. Instructors and students confirm that this feature enhances comprehension of chapter material and deepens understanding of the scientific process itself—a key component of effective citizenship in today's science-driven world.

"Science behind the Story" tells students about the science of the environment in Canada and around the globe, and about the important work of Canadian environmental scientists internationally. This edition showcases many new "Science behind the Story" features, including

- **Chapter 5:** Ecological Recovery at Mount St. Helens
- **Chapter 6:** A Different Population Bomb: The "Household Explosion"
- **Chapter 9:** Counting Species in the World's Most Biodiverse Place
- **Chapter 10:** Assisted Migration: Getting Trees Where They Need to Go in a Changing Climate
- **Chapter 11:** Near-Death Experience at the Experimental Lakes Area
- **Chapter 15:** Keystone XL, Northern Gateway, and the Dilbit Controversy
- **Chapter 16:** Weighing the Impacts of Solar and Wind Development
- **Chapter 17:** Mount Polley Tailings Dam Failure
- **Chapter 18:** Edmonton Showcases Reduction and Recycling
- **Chapter 20:** Ethics and Intergenerationality in Economics: Discounting, Climate Change, and the Stern Review
- **Chapter 21:** The Great Lakes and the International Joint Commission

End-of-Chapter Features

Each chapter concludes with features that facilitate review and develop critical thinking skills. "Reviewing Objectives" summarizes each chapter's main points and relates them to the learning objectives presented at the beginning of each chapter, enabling students to confirm that they have understood the most crucial concepts. "Testing Your Comprehension" questions provide concise study questions targeted at main topics in each chapter, while "Thinking It Through" questions encourage broader creative thinking aimed at finding solutions. "Interpreting Graphs and Data" uses figures from recent scientific studies to help students build quantitative and analytical skills in reading graphs and tables, and making sense of data.

MasteringEnvironmentalScience

With this edition we are thrilled to offer expanded opportunities through **MasteringEnvironmentalScience**, our powerful yet easy-to-use online learning and assessment platform. We have developed new content and activities specifically to support features in the textbook, thus strengthening the connection between these online and print resources. This approach encourages students to practise their science literacy skills in an interactive environment with a diverse set of automatically graded exercises. Students benefit from self-paced activities that feature immediate wrong-answer feedback, while instructors can gauge student performance with informative diagnostics. By enabling assessment of student learning outside the classroom, **MasteringEnvironmentalScience** helps the instructor maximize the impact of in-classroom time. As a result, both educators and learners benefit from an integrated text and online solution.

- "Pearson eText" gives students access to the text whenever and wherever they have online access to the internet. eText pages look exactly like the printed text, offering powerful new functionality for students and instructors. Users can create notes, highlight text in different colours, create bookmarks, zoom, click hyperlinked words and phrases to view definitions, and view in single-page or two-page view.
- "Process of Science" activities help students navigate the scientific method, guiding them through in-depth explorations of experimental design using "Science behind the Story" features. These activities encourage students to think like a scientist and to practise basic skills in experimental design.
- "Interpreting Graphs and Data": "Data Q" activities pair with the new in-text "Data Analysis Questions" and coach students to further develop skills related to presenting, interpreting, and thinking critically about environmental science data.
- "First Impressions" Pre-Quizzes help instructors determine their students' existing knowledge of environmental issues and core content areas at the outset of the academic term, providing class-specific data that can then be employed for powerful teachable moments throughout the term.
- "Video Field Trips" allow the instructor to kick off class with a short visit to a wind farm, a site tackling invasive species, or a sustainable campus.

- "Interpreting Graphs and Data" exercises and the interactive "GraphIt!" program guide students in exploring how to present and interpret data and how to create graphs.
- "Viewpoints" are paired essays, which are authored by invited experts who present divergent points of view on topical questions.

The Teaching and Learning Package for the Instructor

We have prepared an excellent supplements package to accompany the text.

Instructor Resources The instructor resources are available online via the Instructor Resources section of **MasteringEnvironmentalScience®** and **http://catalogue.pearsoned.ca**. The following supplements are designed to facilitate lecture presentations, encourage class discussions, aid in creating tests, and foster learning:

- The **Instructor's Manual** includes lecture outlines, teaching notes that integrate material from the chapter, discussions of "The Science behind the Story" features, suggestions for supplementary print and online resource material, and solutions to end-of-chapter questions and problems.
- The **Test Item File** is a test bank that contains approximately 1400 questions and includes multiple-choice, short-answer, graphing, and scenario-based items. For all questions, we identify a suggested answer, an associated learning objective, and a difficulty level of easy, moderate, or difficult.
- The **Computerized Testbank (Pearson TestGen™)** presents the testbank in a powerful program that enables instructors to view and edit existing questions, create new questions, and generate quizzes, tests, exams, or homework. TestGen also allows instructors to administer tests on a local area network, have the tests graded electronically, and have the results prepared in electronic or printed reports. The Pearson TestGen is compatible with Windows or Mac systems.
- The **PowerPoint Presentations** are available in Microsoft PowerPoint®. The colourful slides highlight, illuminate, and build on key concepts in the text.
- The **Image Library** is an impressive resource to help instructors create vibrant lecture presentations. Almost every figure and table from the text is provided in electronic format and is organized by chapter for convenience. These images can be imported easily into Microsoft PowerPoint to create new presentations or to add to existing ones.

Pearson's Learning Solutions Managers Learning Solutions Managers work with faculty and campus course designers to ensure that Pearson technology products, assessment tools, and online course materials are tailored to meet your specific needs. This highly qualified team is dedicated to helping schools take full advantage of a wide range of educational resources, by assisting in the integration of a variety of instructional materials and media formats. Your local Pearson sales representative can provide you with more details on this service program.

Acknowledgments

A textbook is the product of *many* more minds and hearts than one might guess from the names on the cover. All three of us have been exceedingly fortunate to be supported and guided, through this and previous editions of the book, by a tremendous publishing team and a small army of experts in environmental science who have generously shared their time and expertise. Although we alone, as authors, bear responsibility for any inaccuracies, the strengths of this book result from the collective labour and dedication of innumerable people.

As the author of the Canadian edition I am extremely grateful to the team at Pearson Canada for its support, advice, and professionalism throughout the development of the Canadian editions. First of all, many thanks to Sherry Zweig, who first got me involved with this project and with Pearson Canada, for her continuing support and friendship. Special thanks go to Joanne Sutherland, Developmental Editor, and Susan Bindernagel, Production Editor and Proofreader, for bearing with me through all of the inevitable delays and frustrations, and never losing faith, and to Cathleen Sullivan and Lisa Rahn, Executive Acquisitions Editors, and Darryl Kamo, Program Manager. Other members of the Pearson Canada team whose contributions to this project (not to mention their patience and professionalism) were crucially important include Söğüt Y. Güleç, Copy Editor; Jessica Hellen and Jessica Mifsud, Project Managers; Kathryn O'Handley, Permissions Project Manager; Kimberley Teska, Marketing Manager; Anthony Leung, Senior Designer; and Vignesh Sadhasivam, photo researcher from Integra. Francine McCarthy, Technical Proofreader, made me shake my fist but also made many valuable contributions to the text. It is a pleasure to work with such a talented and committed group of people.

I also want to extend my deep appreciation to my colleague and friend, Monika Havelka, whose creative ideas, experience teaching with the book, and insights from being the other half of my brain have been invaluable.

And for the third Canadian edition, I would once again like to thank my ever-patient family, who happily put up with a perpetually temporary office on the dining room table. My son Riley King and my daughter Eliza King also contributed editorial and research assistance, at times when they were really needed. I also want to acknowledge the assistance of my colleagues (especially Professors Andrea Olive, Nick Collins, and Kent Moore), Educational Resources Assistant Jennifer Soehner, my friends (especially the Lost Trio Hiking Association), and generations of ENV100 students at the University of Toronto Mississauga.

We dedicate this book to today's students, who will shape tomorrow's world.

—Barbara Murck
(for Jay Withgott and Matthew Laposata)

Reviewers

We have been guided in our efforts by extensive input from colleagues across Canada who have served as reviewers and advisors for the first and second Canadian editions, in addition to the contributions of many reviewers for the U.S. editions. The participation of so many learned and thoughtful experts has improved the book in countless ways and has made this edition much stronger. Sometimes you made me shake my fist at my laptop, but in the end your insightful comments and suggestions led to a much stronger book. If the thoughtfulness and thoroughness of these reviewers are any indication, then the teaching of environmental science in Canada is in excellent hands!

Clem Bamikole, *Georgian College*
Darren Bardati, *Bishop's University*
Sarah Boon, *University of Lethbridge*
John Buskard, *Concordia University*
Steven J. Cooke, *Carleton University*
Mario Corbin, *Champlain College Lennoxville*
Tim Elkin, *Camosun College*
Mariola Maya Janowicz, *Concordia University College of Alberta*
Jeff Lewis, *Vancouver Island University*
Brian O'Neill, *Holland College*
Ben Rubin, *University of Western Ontario*
Yolanda Spithoven, *University of New Brunswick*
Lorraine Vanderzwet, *Mohawk College of Applied Arts and Technology*

About the Authors

Jay H. Withgott has authored *Environment: The Science behind the Stories* as well as its brief version, *Essential Environment*, since their inception. In dedicating himself to these books, he works to keep abreast of a diverse and rapidly changing field and continually seeks to develop new and better ways to help today's students learn environmental science.

As a researcher, Jay has published scientific papers in ecology, evolution, animal behaviour, and conservation biology in journals ranging from *Evolution* to *Proceedings of the National Academy of Sciences*. As an instructor, he has taught university lab courses in ecology and other disciplines. As a science writer, he has authored articles for numerous journals and magazines including *Science, New Scientist, BioScience, Smithsonian*, and *Natural History*. By combining his scientific training with prior experience as a newspaper reporter and editor, he strives to make science accessible and engaging for general audiences. Jay holds degrees from Yale University, the University of Arkansas, and the University of Arizona.

Jay lives with his wife, biologist Susan Masta, in Portland, Oregon.

Matthew Laposata joined the writing team for the fifth U.S. edition of *Environment: The Science behind the Stories*. Matt is a professor of environmental science at Kennesaw State University (KSU). He holds a bachelor's degree in biology education from Indiana University of Pennsylvania, a master's degree in biology from Bowling Green State University, and a doctorate in ecology from The Pennsylvania State University.

Matt is the coordinator of KSU's two-semester general education science sequence titled Science, Society, and the Environment, which enrolls roughly 6000 students per year. He focuses exclusively on introductory environmental science courses and has enjoyed teaching and interacting with thousands of nonscience majors during his career. He is an active scholar in environmental science education and has received grants from state, federal, and private sources to develop and evaluate innovative curricular materials. His scholarly work has received numerous awards, including the Georgia Board of Regents' highest award for the Scholarship of Teaching and Learning.

Matt resides in suburban Atlanta with his wife, Lisa, and children, Lauren, Cameron, and Saffron.

Barbara Murck has authored the Canadian editions of *Environment: The Science behind the Stories* from the beginning. Barb has taught environmental and Earth science at the University of Toronto Mississauga (UTM) for more than 30 years. Her academic background is in geology, with an undergraduate degree from Princeton University and Ph.D. from the University of Toronto.

Barb has worked on a wide variety of environmental management projects in the developing world, from Africa to Asia, mainly as an expert on training and curriculum development. She has published numerous books on topics ranging from physical geology to environmental science to sustainability. She was honoured with the University of Toronto President's Teaching Award in 2010. A current much-loved project is teaching a field course each summer in the Ecuadorian Andes, the Amazon, and the Galápagos Islands. Barb has greatly appreciated having had the opportunity to influence the lives and learning of thousands of UTM students over the years.

Barb lives with her family, including her two kids and the world's best dogs, in a 115-year-old house in Southern Ontario. When not at work, she is likely to be found hiking the Bruce Trail, the oldest and longest marked hiking trail in Canada.

About Our **Sustainability Initiatives**

This book is carefully crafted to minimize environmental impact. The materials used to manufacture this book originated from sources committed to responsible forestry practices. The printing, binding, cover, and paper come from facilities that minimize waste, energy consumption, and the use of harmful chemicals.

Pearson closes the loop by recycling every out-of-date text returned to our warehouse. We pulp the books, and the pulp is used to produce items such as paper coffee cups and shopping bags. In addition, Pearson has become the first climate-neutral educational publishing company.

The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content, and to do so in ways that minimize our environmental impact.

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About the Cover …

Cover image: *Colorado River Delta #2 Near San Felipe, Baja, Mexico, 2011*

"My hope is that these pictures will stimulate a process of thinking about something essential to our survival; something we often take for granted—until it's gone."

—Edward Burtynsky

Canadian photographer Edward Burtynsky has devoted his career to documenting our conflicted relationship with the natural environment, particularly the transformation of landscapes by industrial activity. With his Water project, Burtynsky undertook to understand and document our use and abuse of water; our cover photo is part of the resulting series. It shows the Colorado River delta, once a vast tidal estuary flowing into the Gulf of California. The delta and its unique and biodiverse ecosystems were fundamentally degraded by decades of water diversion from the river. In the late 1990s, however, the delta began a slow revival. Releases of water from reservoirs, return flows of agricultural irrigation water, flood water, and even flows of municipal waste water, although polluted and saline, have restored some parts of the delta ecosystem. Water is beginning to flow, where once there was only a desert.

Like most of Burtynsky's photos, the image on our cover makes us stop and think about the impacts of our activities on the things that we depend upon most fundamentally. His images are complicated and contradictory, like our relationships with the natural environment. We are centrally dependent on environmental goods and services to support our lives and our lifestyles; yet, by our very presence and activities, we degrade and destroy those resources. But human actions are also capable of reversing or mitigating those negative impacts, as we see in this image showing the tentative recovery of the Colorado River delta. Burtynsky's photos thus typically contain an element of despair and even horror amidst the beauty: "We did that… ?!" But the despair is mixed with hope that things can change.

In *Environment: The Science behind the Stories*, Third Canadian Edition, as in the previous editions, we look for scientific evidence of our use of environmental resources, our impacts on those resources, and the effectiveness of our efforts to mitigate the impacts. We try to guide students through the complexities of the discipline, and encourage them to think for themselves about the natural world, what science can and cannot tell us, and the impacts of their own attitudes and lifestyle choices on the environment. We have always tried to distinguish, clearly, between environmental science as a scientific discipline, and environmentalism as an advocacy movement; yet, in the end, they come together. Because we are *of* the world, not just *in* it, we are part of the environment, and everything we do (and even what we think) necessarily has impacts. In our modern world we all have a responsibility to be conscious of the impacts of our choices. Burtynsky's photos address these complexities and contradictions head-on, and that is why we have chosen them to be on the covers of all three Canadian editions.

PART ONE

Foundations of Environmental Science

Combers Beach in Pacific Rim Reserve, British Columbia, is part of Canada's National Parks system.

Rolf Hicker/All Canada Photos

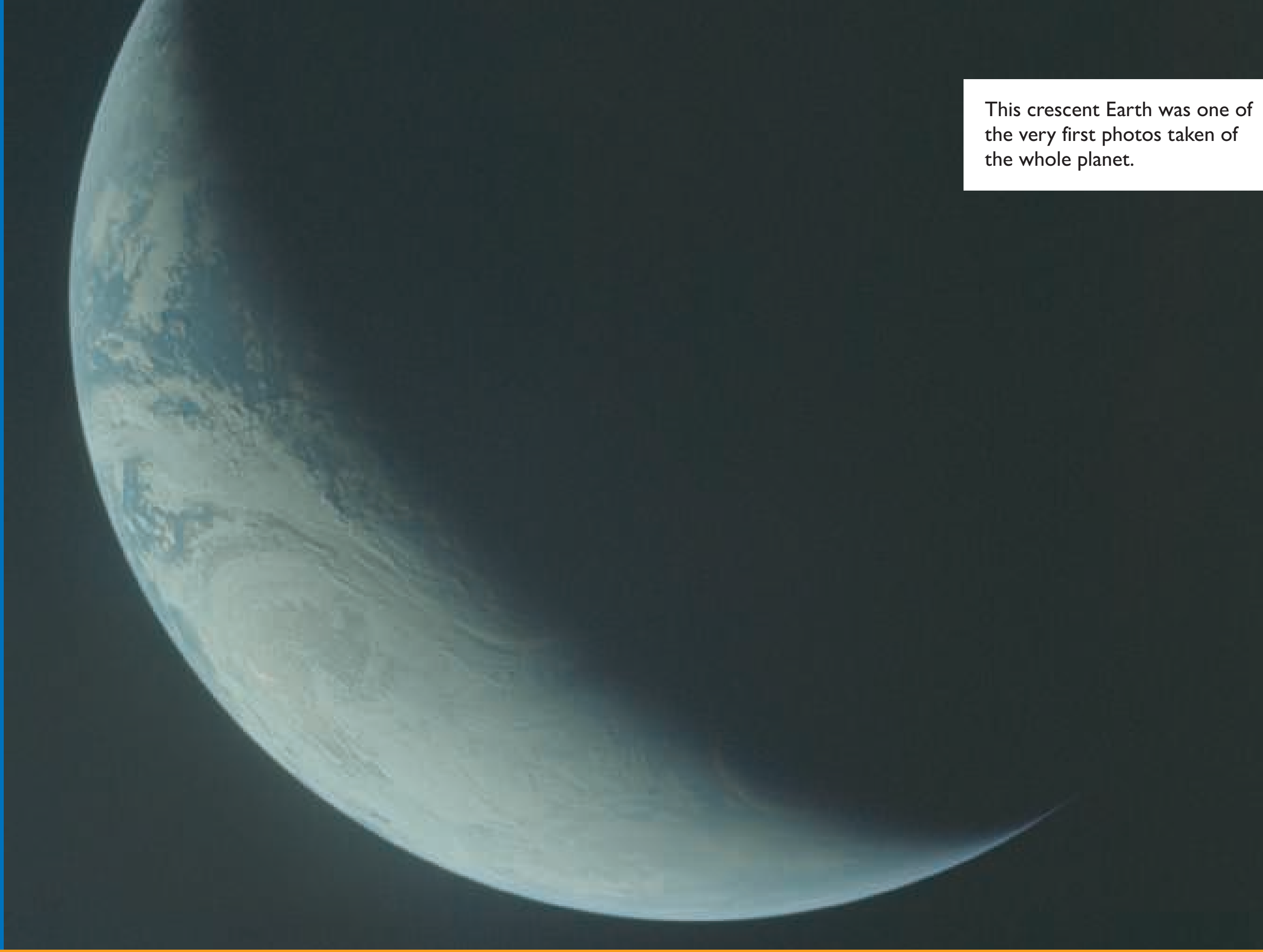
1 An Introduction to Environmental Science

Earth is like an island in space.

NASA/Visible Earth

Upon successfully completing this chapter, you will be able to

- Define the term *environment*
- Characterize the interdisciplinary nature of environmental science
- Describe several types of natural resources and explain their importance to human life
- Diagnose and illustrate some of the pressures on the global environment
- Articulate the concepts of sustainability and sustainable development



This crescent Earth was one of the very first photos taken of the whole planet.

NASA

CENTRAL CASE

EARTH FROM SPACE: THE POWER OF AN IMAGE

"The two-word definition of sustainability is 'one planet.' "

—MATHIS WACKERNAGEL, ECOLOGICAL ECONOMIST AND CO-DEVELOPER OF THE ECOLOGICAL FOOTPRINT CONCEPT

"We're not the first to discover this, but we'd like to confirm, from the crew of *Apollo 17*, that the world is round."

—EUGENE CERNAN, *APOLLO 17* COMMANDER

C*onsider the following:* Prior to November 9, 1967, no one had *ever seen* a photograph of the whole planet Earth, because no such thing existed.

Those of us who were alive back in 1967 were not completely clueless. We knew that Earth is a planet, surrounded by space. We knew that Earth is round (although visual confirmation of this fact still made a considerable impact on *Apollo 17* astronauts a few years later). Yet a simple photograph of Earth—floating in space, blue and shining and covered by clouds, vegetation, and a whole lot of water—managed to take everyone by surprise and changed both society and history in the process.

Actually, the very first photographs of the whole Earth, taken in 1967, were not the ones that eventually caught the imagination of the general public. The 1967 photographs were taken by automated camera from the unmanned *Apollo 4* spacecraft, the first spacecraft to get far enough away from Earth to photograph the entire planet. Only part of the planet was in sunlight, so the photographs show only a "crescent" Earth (see photo). Not long after, on December 24, 1968, *Apollo 8* astronauts took the first handheld photographs showing Earth rising over the horizon of the Moon (the closing photo of this book). The crew did a live radio broadcast that day, during which astronaut James Lovell commented, "The Earth from here is a grand oasis in the big vastness of space."[1]

It was not until 1972 that the *Apollo 17* mission put astronauts in a position to photograph the entire *illuminated* planet Earth. The result was the famous Blue Marble[2] image, a version of which opens this chapter. The photograph was beautiful, its impact stunning, even unsettling. The original image was oriented with Antarctica at the top of the globe and an "upside-down" Africa in the middle. The unfamiliar perspective caused consternation among those who had never stopped to consider that the convention of orienting maps with north at the top is completely arbitrary.

The Blue Marble photograph is widely credited with kick-starting the modern environmental movement. Just five years elapsed between the first whole-Earth photographs in 1967 and the last ones to be recorded by human hands. Since 1972, no manned space flight has been far enough away for the planet to be photographed in its entirety by astronauts. In that five-year period was the summer of love, and war—the Vietnam War, the Six Day War, the Cold War. The Beatles sang on the first live international satellite television production. Canada celebrated the hundredth year of Confederation. Neil Armstrong became the first person to walk on the Moon. Civil rights activist Martin Luther King, Jr., died; so did J. Robert Oppenheimer, the "father of the atomic bomb." The first handheld calculator was sold (for almost $400).

Society changed dramatically during those five years, and it was a period of dawning awareness and public involvement in environmental issues. The first major oil spill happened in 1967 when the *Torrey Canyon* ran aground near England with 120 000 metric tons of crude oil on board. The first hints of trouble began to surface (literally) from hazardous chemicals stored underground at Love Canal, New York. Within a few years the site would be infamous, leading to the first declaration of an environmental state of emergency in the United States and making a grassroots hero of local activist Lois Gibbs. Books on environmental topics began to appear on bestseller lists, including *Limits to Growth,*[3] *The Population Bomb*,[4] *Small Is Beautiful,*[5] and their predecessor, *Silent Spring*.[6] The 1970s opened with the signing of the first federal environmental legislation, the United States' *Environmental Protection Act* (1970). The first Earth Day was held (1970). Greenpeace was founded (1971). The *United Nations Environment Programme* was established (1972).[7]

British astronomer Sir Frederick Hoyle is reputed to have said in 1948, "Once a photograph of the Earth, taken from outside, is available—once the sheer isolation of the Earth becomes known—a new idea as powerful as any in history will be let loose." To what extent were the milestones of environmental history descended from the first glimpses of our planet from space, with all of its fragility and limitations? We will never know, but the Blue Marble is still considered to be one of the most influential photographs in history—possibly the most widely distributed image of all time—and it remains an iconic symbol of the modern environmental movement.

Our Island, Earth

Viewed from space, our home planet appears suspended against a vast inky-black backdrop. Although few of us will ever witness that sight directly, photographs taken from space convey a sense that Earth is like an island—small, isolated, and finite. Yet this island supports all of the vastness and complexity of life as we know it.

The environment is more than just our surroundings

A photograph from space reveals a great deal, but it does not adequately convey the complexity of the environment. Our **environment** is more than water, land, and air; it is the sum total of our surroundings. It includes all of Earth's **biotic** components, or living things, and **abiotic** components, the nonliving things with which we interact. The abiotic constituents include the continents, oceans, clouds, rivers, and icecaps that you can see in a photo of Earth from space. The biotic constituents are the animals, plants, forests, soils, microbes, and people that occupy the landscape. In a more inclusive sense, the environment also encompasses the built environment, including the urban centres, living spaces, and physical infrastructure that humans have created. In its *most* inclusive sense, the environment includes the complex webs of scientific, ethical, political, economic, and social relationships and institutions that shape our daily lives.

People often use the term *environment* in a narrower sense, though, referring to a "natural" world that stands apart from human society. This connotation is unfortunate, because it masks the important fact that humans exist within the environment and are an integral part of the interactions that characterize and shape it. As just one of many species, we share with the others a fundamental dependence on a healthy, functioning planet. The limitations of language make it all too easy to speak of "people and nature," or "society and the environment," or even "environment versus economy," as though they were separate, not interconnected, or in conflict. Fundamentally, we exist as part of the natural world, and our interactions with the other parts matter a great deal.

"Environment" has legal, social, economic, and scientific aspects

Why is it important that we give such careful consideration to the meaning of the term *environment?* Back in 1971, when the federal government passed Canada's first environmental legislation, the environmental awareness of most North Americans was limited. If they thought about it at all, most people would have equated *environment* with *wilderness*. This oversimplification changed as public consciousness of environmental issues grew. Wilderness preservation is still an important concern, but our understanding of the environment, our impacts on it, and its role in our health and daily lives has broadened dramatically since then.

Today our definition of the term *environment* must be sufficiently comprehensive to include its legal, social, economic, and scientific aspects. Business management, politics, ethics, international relations, economics, social equity, engineering, law enforcement, and chemical, physical, geological, and biological sciences—all of these play a role in managing and protecting both people and the natural environment. Consequently, the mandate of **Environment Canada**, the department of the federal government that is most directly responsible for the protection of the environment, is also very comprehensive. Among other things, the role of Environment Canada includes preserving and enhancing the quality of the natural environment, protecting and conserving renewable resources and water resources, enforcing Canada's sovereignty over our boundary waters, and forecasting weather conditions and warnings.[8]

To accomplish all of this, our environmental leaders and policymakers need to know what they are talking about; this is the main reason that Environment Canada was established as a science-based organization. As a community, we must constantly improve and refine our basic scientific understanding of water, air, land and soils, wildlife, weather and climate, and the dynamic interactions among all the components of which ecosystems are composed. This is where *environmental science*—the central focus of this book—comes in.

Environmental science explores interactions between people and the natural world

Environmental science is the study of how the natural world works, how our environment affects us, and how we affect our environment. Appreciating how we interact with the physical and biological environment is crucial for a well-informed view of our place in the world, and for a mature awareness that we are one species among many on a planet full of life. As our population, our technological powers, and our consumption of resources increase, so does our ability to alter our planet and damage the very systems that keep us alive. We need to understand these impacts more thoroughly and manage them more effectively. Environmental science emerged in the latter half of the twentieth century in response to this need.

Understanding the functioning of the natural environment and our role in it, our interactions with it, and our impacts on it is the essential first step toward finding solutions to our most pressing environmental problems. Part 1 of this book, *Foundations of Environmental Science*, takes that first step by providing an introduction to the materials and processes that characterize the biotic and abiotic components of the environment, and the basic concepts and principles of science as applied to the study of the environment.

It can be daunting to reflect on the number and magnitude of environmental dilemmas that confront us today. Many environmental scientists are trying to apply their knowledge to develop practical solutions to the environmental challenges we face. We examine these challenges and issues in Part 2, *Issues, Impacts, and Solutions*, starting with a look at the human population itself and how it has grown and changed over time.

Fortunately, with problems also come opportunities for devising creative solutions. Right now, global conditions are changing more quickly than ever. Right now, through science, we as a civilization are gaining knowledge more rapidly than ever. And right now, the window of opportunity for acting to solve problems is still open. With such bountiful challenges and opportunities, this particular moment in history is an exciting time to be studying environmental science.

The Nature of Environmental Science

Environmental scientists strive to understand how Earth's natural systems function, how humans are influenced by those systems, and how we are influencing those systems. In addition, many environmental scientists are motivated by a desire to develop solutions to environmental problems. The solutions themselves (such as new technologies, policy decisions, or resource management strategies) are applications of environmental science. The study of such applications and their consequences is also part of environmental science.

Science is a systematic process for learning about the world

Environmental science is part of the broader human endeavour of **science**, a systematic process for learning about the world and testing our understanding of it. The term *science* also refers to the accumulated body of knowledge that arises from this dynamic process of observation, testing, and discovery, which we will explore in greater detail in the chapter *Matter, Energy, and the Physical Environment*.

Knowledge gained from science can be applied to societal problems. Among the most important applications of science are its use in developing new technologies, and informing policy and management decisions (**FIGURE 1.1**). These pragmatic applications in themselves are not science, but they must be informed by science in order to be effective. Many scientists are motivated simply by a desire to know how the world works, and others are motivated by the potential for developing useful applications and solutions to problems.


Courtesy of Jay Withgott

FIGURE 1.1
Scientific knowledge can be applied in policy and management decisions and in technology. Prescribed burning, shown here, is a management practice that is used to restore healthy forests, and is informed by scientific research into forest ecology.

Why does science matter? The late American astronomer Carl Sagan wrote the following in his 1995 treatise *The Demon-Haunted World: Science as a Candle in the Dark:*

> *We've arranged a global civilization in which the most crucial elements—transportation, communications, and all other industries; agriculture, medicine, education, entertainment, protecting the environment; and even the key democratic institution of voting—profoundly depend on science and technology.*[9]

Sagan and many others have argued that science is essential if we hope to develop solutions to the problems—environmental and otherwise—that we face today. We can go a step further and suggest that the *democratization* of science—making the science of our world accessible and understandable to as many people as possible—is also essential if we are to make informed decisions about the management of this planet. That is one reason why it is important for you to learn as much as possible about the science of the environment, and to pass along some of that knowledge to others.

Scientific ideas and methods change and evolve as new information is discovered, ideas are tested, and knowledge grows. Understanding how science works is especially relevant in environmental science, a young field that is changing rapidly as we gather vast amounts of new information, as human impacts on the planet multiply, and as lessons from the consequences of our actions become apparent. Because so much remains unstudied and undone, and because so many issues we cannot foresee are likely to arise in the future, environmental science will remain an exciting frontier for you to explore as a student and as an informed citizen throughout your life.

Environmental science is an interdisciplinary pursuit

Like science in general, environmental science informs practical applications and can be motivated by them. Studying natural systems and addressing environmental problems are complex endeavours that require expertise from many disciplines. Environmental science is thus an **interdisciplinary** field of study—one that employs concepts and techniques from numerous disciplines and brings research results from these disciplines together into a broad synthesis (**FIGURE 1.2**). Traditional disciplines (such as biology, geology, and chemistry) are valuable because their scholars delve deeply into topics, uncovering new

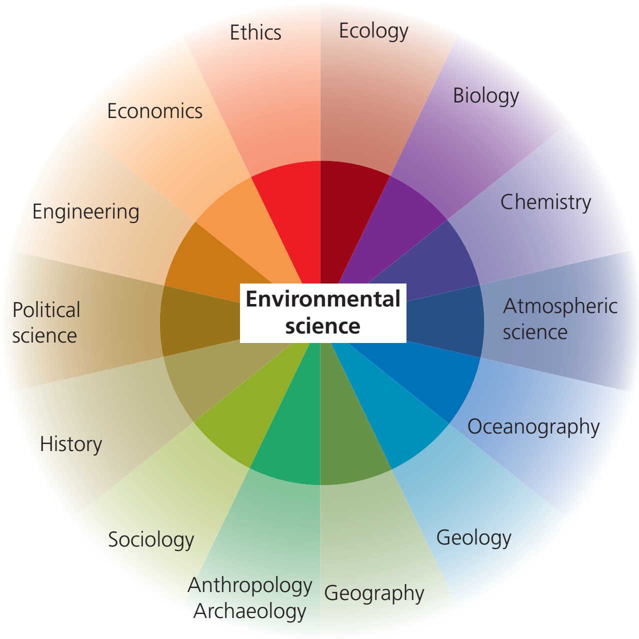


FIGURE 1.2
Environmental science is an interdisciplinary pursuit, involving input from many different established fields of study across the natural and social sciences.

knowledge and developing expertise in particular areas. Interdisciplinary fields are valuable because their practitioners take specialized knowledge from different disciplines, consolidate it, synthesize it, and apply it in a broad context to serve the multifaceted interests of society.

Environmental science is especially broad because it encompasses not only the *natural sciences* (disciplines that study the natural world) but also the *social sciences* (disciplines that study human interactions and institutions). The natural sciences provide us with the means to gain accurate information about the physical environment and to interpret it reasonably. Addressing environmental problems, however, also involves weighing values and understanding human behaviour, and this requires the social sciences. Most environmental science programs in universities focus predominantly on the natural sciences as they pertain to environmental issues. Programs that heavily incorporate the social sciences often prefer the term *environmental studies* or *environmental management* to describe their academic umbrella. Whichever approach we take, these fields reflect many diverse perspectives and sources of knowledge.

Just as an interdisciplinary approach to studying issues can help us better understand them, an integrated approach to addressing problems can help us produce effective and lasting solutions. For example, consider how the Canadian mining industry approaches the problem of acid mine drainage, which can occur when sulphur is present at a mine site. Sulphur is a common constituent of coal and metal ores, both of which are important to the Canadian economy. If sulphur-bearing waste rock at a mine site interacts with rain or surface water, sulphuric acid is formed; if not contained, the acid can enter local streams, where it is devastating to affected ecosystems. To solve a problem involving *acid drainage*, a mining company could consult a biologist or an ecologist regarding the impacts of the acid on local plants and animals. A hydrologist would be helpful, to understand the flow of water at the site. A mining engineer could help decide how best to contain and isolate the waste rock piles. The company could consult with a chemist about the nature and behaviour of the acidic solution, and how it interacts with rocks and soils. Someone skilled at management would be helpful, to act as a liaison between the scientists and the mine management team. Canadian mining companies routinely make use of teams like this in their efforts to control acid mine drainage.

Environmental science is not the same as environmentalism

Although many environmental scientists are interested in solving problems, it is incorrect to confuse environmental science with environmentalism or environmental activism. They are *not* the same. Environmental science is the pursuit of scientific knowledge about the workings of the environment and our interactions with it. **Environmentalism** is a social movement dedicated to protecting the natural world—and, by extension, humans—from undesirable changes brought about by human choices (**FIGURE 1.3**).

Sean Kilpatrick/The Canadian Press

FIGURE 1.3
Environmental scientists play roles very different from those of the environmental activists shown here. Some scientists do become activists to promote what they feel are workable solutions to environmental problems; most try to keep their advocacy separate from their scientific work. This photograph shows Greenpeace activists protesting on Parliament Hill in Ottawa. Greenpeace was founded in Vancouver in 1971.

These immense *moai* statues are iconic symbols of Rapa Nui, or Easter Island.
Viktorus/Shutterstock

THE SCIENCE BEHIND THE STORY

The Lesson of Rapa Nui

Rapa Nui (or Easter Island) is a small island in the Pacific and one of the most remote inhabited places on the globe. When European explorers reached the island in 1722, they found a barren landscape populated by fewer than 2000 people living a marginal existence in caves. The island featured gigantic statues of carved stone, called *moai*, evidence that a sophisticated civilization had once lived there.

How could people without wheels or rope, on an island without trees, have moved statues 10 m high, weighing 80 metric tons? The answer lies in the fact that the island did not always lack trees, and its people were not always without rope. The island was once lushly forested, supporting a prosperous society of 6000 to 30 000 people. What happened? Many researchers have tried to solve the mystery.

A key discovery, based on many lines of evidence, was that the island was once forested. British scientist John Flenley and colleagues[10] drilled cores deep into lake sediments and examined ancient pollen grains preserved there. Finding a great deal of palm pollen, they inferred that the island had been covered with tall palm trees. Archaeologists also found ancient palm nut casings buried in soil near carbon-lined channels made by palm roots, and researchers deciphering script on stone tablets discerned characters etched in the form of palm trees.

By studying pollen and the remains of wood from charcoal, archaeologist Catherine Orliac[11] found that at least 21 other plant species—now gone—had also been common. Clearly, the island had supported a diverse forest. Forest plants would have provided fuelwood, building material for houses and canoes, fruit to eat, fibre for clothing—and, researchers guessed, logs and fibrous rope to help move the enormous *moai* statues.

Pollen analyses showed that trees declined and were replaced by ferns and grasses. Charcoal in the soil showed that forests had been burned, perhaps for slash-and-burn farming. Researchers concluded that the islanders, desperate for forest resources and cropland, had deforested the island. With the forest gone, the soil eroded away, confirmed by data that showed a great deal of sediment accumulating on lake bottoms. Erosion would have lowered crop yields, perhaps leading to starvation.

Wild animals also disappeared. Archaeologist David Steadman analyzed 6500 bones and found that at least 31 bird species originally provided food for the islanders.[12] Today only one native bird species is left. Remains from charcoal fires show that early islanders also feasted on fish, sharks, porpoises, turtles, octopus, and shellfish—but in later years they consumed little seafood.

As resources declined, some researchers concluded, people fell into clan warfare, suggested by unearthed weapons and skulls with head wounds. Rapa Nui appeared to be a tragic case of ecological suicide: A once-flourishing civilization depleted its resources and destroyed itself. In this interpretation, Rapa Nui seemed to offer a clear lesson: We, on planet Earth, had better learn to use our limited resources wisely.

Canadian economists Scott Taylor and James Brander took a different approach.[13] They developed a computer model of the interplay between renewable resources and population. The model is based on standard ecological predator–prey models, with people in the role of predator, and resources as their prey. This scenario generates "feast-and-famine" cycles of rising and falling population and resource stocks. The researchers

Environmental scientists study many of the same processes, locations, and issues that environmentalists care about, but as scientists they attempt to maintain an objective approach in their work. Ideally, science informs and responds to political and social influences, without being overly influenced by them. Remaining as free as possible from personal, political, or ideological bias—and open to whatever conclusions the data demand—is a hallmark of the effective scientist.

Both environmental scientists and individuals in non-scientific professions can make important contributions to the understanding, protection, management, and sustainable use of the natural environment. These people work in a wide range of positions, from policymaker to activist, artist, journalist, business person, hunter, or animal rescuer. Many of them are scientists *and* writers, or scientists *and* filmmakers, or gardeners or politicians or musicians or managers—and, yes, many of them are also environmentalists.

Consider, for example, David Suzuki, who has been called "Canada's environmental conscience." We know him best as a journalist, writer, TV broadcaster, and environmental activist, but Suzuki originally trained and started his career as a scientist—a professor of genetics. His background in science informs his advocacy; however, he has consciously given up "doing" science on an everyday basis, choosing instead to focus on more political questions. David Suzuki's career demonstrates that environmental science and environmentalism are different, but not entirely or necessarily separate.

Science is a human endeavour; it can never be entirely free of political or social influence. We want our leaders to incorporate scientific understanding into their social decisions, but there is no foolproof way to ensure that

La Tercera/AP Images

Archaeological investigations, like this one by the Easter Island Statue Project, aim to understand and preserve the cultural legacy of the islanders.

speculated that such cycles may account for the decline and eventual collapse of civilizations like that of Rapa Nui, as a result of rapid population growth and consequent resource degradation.

Anthropologist Terry Hunt and archaeologist Carl Lipo drew entirely different conclusions from their scientific findings.[14] When they began their research on Rapa Nui in 2001, they expected simply to help fill gaps in a well-understood history. But science is a process of discovery, and sometimes evidence leads researchers far from where they anticipated. Hunt and Lipo ended up convinced that nearly everything about the traditional "ecocide" interpretation was wrong.

Their findings suggested that deforestation occurred rapidly, shortly after the arrival of the first colonists. How could so few people have destroyed so much forest so fast? Their answer: rats. When Polynesians settled new islands, they brought crop plants, domestic animals such as chickens, and rats. Rats multiply quickly, and they soon overran Rapa Nui.

The rats ate palm nuts—perhaps so many that the trees could not regenerate. With no young trees growing, the palm went extinct. Despite the forest loss, Hunt and Lipo argue that islanders were able to persist and thrive, adapting to Rapa Nui's poor soil and windy weather by developing rock gardens to protect crops. Tools that previous researchers viewed as weapons were actually farm implements, they concluded; lethal injuries were rare, and no evidence of battle or defensive fortresses was uncovered.

The evidence led Hunt and Lipo to propose that the islanders had acted as responsible stewards of the island's resources. The eventual collapse of this civilization, they argue, came with the arrival of Europeans, who unwittingly brought contagious diseases to which the islanders had never been exposed. Before that, Hunt and Lipo say, Rapa Nui's people maintained a peaceful and resilient society for 500 years.

This interpretation represents a shift in how we view Rapa Nui. Were the early inhabitants good environmental stewards who were overcome by insurmountable outside forces? Or did they overuse and deplete the island's resource base, initiating the decline and collapse of the civilization? Debate between the two camps remains heated, and research continues as scientists look for new ways to test the differing hypotheses. In the long term, data from additional studies should lead us closer and closer to the truth.

science is not misused to serve political ends. By becoming aware of the complex relationships among science, society, and politics, we can work to ensure that an appropriate balance is maintained. Environmental science is *distinct* from politics, law, commerce, philosophy, religion, art, and activism, but is it *exclusive* of these human undertakings? You will have to judge for yourself, but you can count on this book to help you make a more informed judgment of what you read, hear, and experience in your encounters with the natural environment.

Environmental science can help us avoid mistakes made in the past

Today we are confronted with news and predictions of environmental catastrophes on a regular basis, but it can be difficult to assess the reliability of such reports. It is even harder to evaluate the causes and effects of environmental change. Perhaps most difficult is to devise effective solutions to environmental problems. Studying environmental science will outfit you with the tools to evaluate information on environmental change, and think critically and creatively about possible actions to take in response. These tools can help us do better in the future, and avoid some of the mistakes that have been made in the past in our interactions with the environment.

There is historical evidence that civilizations may crumble when pressures from population and consumption overwhelm resource availability (see "The Science behind the Story: The Lesson of Rapa Nui"). Many great civilizations have fallen after depleting resources or damaging their environment. The Greek and Roman empires show evidence of this, as do the civilizations of the Maya, the Anasazi, and other New World peoples. Plato wrote of