Third Edition

Margaret Robertson

Sustainability
Principles and Practice

earthscan
from Routledge

Sustainability Principles and Practice

Sustainability Principles and Practice gives an accessible and comprehensive overview of the interdisciplinary field of sustainability. The focus is on furnishing solutions and equipping the student with both conceptual understanding and technical skills. Each chapter explores one aspect of the field, first introducing concepts and presenting issues, then supplying tools for working toward solutions. Elements of sustainability are examined piece by piece, and coverage ranges over ecosystems, social equity, environmental justice, food, energy, product life cycles, cities, and more. Techniques for management and measurement as well as case studies from around the world are provided.

The 3rd edition includes greater coverage of resilience and systems thinking, an update on the Anthropocene as a formal geological epoch, the latest research from the IPCC, and a greater focus on diversity and social equity, together with new details such as sustainable consumption, textiles recycling, microplastics, and net-zero concepts. The coverage in this edition has been expanded to include issues, solutions, and new case studies from around the world, including Europe, Asia, and the Global South.

Chapters include further reading and discussion questions. The book is supported by a companion website with online links, annotated bibliography, glossary, white papers, and additional case studies, together with projects, research problems, and group activities, all of which focus on real-world problem-solving of sustainability issues.

The textbook is designed to be used by undergraduate college and university students in sustainability degree programs and other programs in which sustainability is taught.

Margaret Robertson is a member of the American Society of Landscape Architects (ASLA) and teaches at Lane Community College in Eugene, Oregon, USA, where she is a coordinator of the Sustainability degree program.

"This is by far the most comprehensive book on sustainability science and practice out there.It should be a core reference for anyone interested in this field. It is also a key source for solutions to creating a sustainable and desirable future for humans and the rest of nature."

—Robert Costanza, Professor, *VC's Chair in Public Policy, Crawford School of Public Policy, The Australian National University, Founding director of the Gund Institute for Ecological Economics, Australia*

"A thorough and dependable guide to the most important issues of our time and what must be done by the rising generation . . . highly recommended for courses across the curriculum."

—David W. Orr, Paul Sears Distinguished Professor Emeritus, Oberlin College, USA

"*Sustainability Principles and Practice* is an outstanding overview of a wide-ranging global discussion that will lead either to human survival or planetary failure. What is sustainable? How are practitioners bringing principles of sustainability into various industries and disciplines? Every thinking person needs to find their place in the sustainability transition, and this book helps by mapping the territory reliably and fairly."

—Richard Heinberg, Senior Fellow, Post Carbon Institute, USA

"*Sustainability Principles and Practice* is like an expertly crafted salad—nutritionally dense and filled with flavor! This is an intense, comprehensive introduction to sustainability. You'll have to chew, but when you're finished you'll be full of new knowledge and definitely satiated!"

—Erik Assadourian, Sustainability Researcher and Educator, USA

Praise for the previous editions

"Achieving sustainability is the single most important challenge facing humanity, and yet few people realize it. If every student read this text the chances of civilization averting a collapse would be substantially improved."

—Paul Ehrlich, Stanford University, USA

"Everyone thinks they know what sustainability is, but few people truly understand it--and fewer still can explain it well. Robertson cuts through the greenwash and the clichés with a top-notch exploration of the topic in all its complexities. It's an enjoyable read that's both thoroughly grounded in science and steeped in wonder at our fascinating, fragile planet."

—Daniel Lerch, Post Carbon Institute, USA

"Margaret Robertson has produced the closest thing yet to a comprehensive textbook on what is a crucial subject. The book provides a grounding in the key challenges while also communicating the potential solutions in a clear and positive fashion. It is equipped to become an essential go-to text for both students of sustainability and those working in the field."

—James Evans, University of Manchester, UK

"This book provides much needed and relevant information on the theory and practice of sustainability. It is comprehensive and useful with practical applications in a wide range of human endeavors."

—Stephen R. Kellert, Yale University, USA

"This book provides a comprehensive overview of the state of our earth systems and what we can do to positively impact change. The book can be used for both undergraduate and graduate education, and across a variety of disciplines. I learned something new at every turn of the page."

—Kevin Dooley, Arizona State University, USA

"The great strength of Robertson's book is its breadth of coverage. From marketing to life cycle costing to the latest science on climate change, *Sustainability Principles and Practice* serves as a welcoming guide into the often jargon-laden field of sustainability."

—Jay Antle, Johnson County Community College, USA

"This book is a solid and well-crafted introduction to the field, conveying both the substance and the heart of sustainability work with style and grace. It will help students and other new entrants to the field get oriented to the special interdisciplinary challenges of sustainability, and to its core mission: helping us learn to be better caretakers of our planetary future."

—Alan AtKisson, President & CEO AtKisson Inc., USA & AtKisson Europe AB, Sweden. President, ISIS Academy GmbH, Germany. Member, President's Science and Technology Advisory Council (PSTAC), European Commission

"This is an important book. Robertson has a keen sense of the situation and an even keener sense of alternatives and means to achieve them. The author gives it to you the way it is and then provides some important pointers to resilient futures. This book contains both a diagnosis and a treatment. Read it."

—Simon Bell, Open University, UK

"An organized, engaging, and even inspiring collection of ideas that—if internalized and used to inform policies—would enable societies to thrive within a healthy environment. I wish this book had been available when I was first learning about social and environmental systems."

—Robert Dietz, Editor, The Daly News*, Center for the Advancement of the Steady State Economy*

"A comprehensive and practical map of the evolving field of sustainability. This well-organized and thoroughly researched textbook provides both students and educators with a useful guide to the essential sustainability topics. Robertson delivers an important work that will help to define the knowledge base in the sustainability field."

—Andrés R. Edwards, Founder, EduTracks, USA. Author of The Sustainability Revolution *and* Thriving Beyond Sustainability

"Robertson places sustainability in the connectedness between human culture and the living world. She links technical knowledge with tools for developing positive solutions and putting them into effect, including working collaboratively in organizations with other people."

—Bruce K. Ferguson, University of Georgia, USA

"Robertson has distilled the essential background information that students, our rising decision-makers, need so that they can follow her clearly defined roadmap to a sustainable future for the planet."

—Lee Kump, Pennsylvania State University, USA

"*Sustainability Principles and Practice* covers a broad range of topics, principles and concepts—at several scales from energy, water, pollution, ecosystems, food, and cities—to a charge to future 'agents for change' at policy, institutional, and personal, experiential levels. A must-have book to refresh your knowledge and to make a better world."

—Alison Kwok, University of Oregon, USA

"From now on when someone asks me what is sustainability, I will tell them to read Margaret Robertson's book, *Sustainability Principles and Practice*, which presents clearly and thoroughly the multi-faceted concept of sustainability in a very readable form."

—Norbert Lechner, Auburn University, USA

"Robertson's incisive analysis is both global and specific, comprehensive and inclusive. There is careful blending of facts and values, what is and what ought to be. You will find yourself engaged. I guarantee it."

—Holmes Rolston, III, Colorado State University, USA

"This book grabbed my attention and kept me engaged. The focus on creating solutions is refreshing. This publication will enhance and deepen the work of any general reader, student or faculty member working to bring sustainability into the curricula."

—Debra Rowe, Oakland Community College, USA

"This book masterfully integrates human and natural systems and the relationships between them into a grand and detailed picture of the world we live in. It provides a highly accessible introduction to sustainability suitable for anyone who cares about where we are going as a species, translating this knowledge into practical action."

—Arran Stibbe, University of Gloucestershire, UK

"This is a comprehensive, useful account of what sustainability is all about and what is needed for building it. It describes the many facets that collectively determine the degree to which a system, at any scale, is sustainable, and explains how they interact. It is a valuable guide and reference for anyone wishing to get involved in the practice of sustainability."

—Brian Walker, CSIRO Ecosystem Sciences, Australia. Author of Resilience Thinking

"Sustainability champions practice systems thinking, connecting the dots between green buildings, sustainable cities, corporate CSR, and all the global sustainability megaforces besieging us. This book is their indispensable primer and wonderfully practical handbook to ensure they are effective change agents. It is a coherent encyclopedia of sustainability issues, with answers."

—Bob Willard, Sustainability Advantage, Canada

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- Throughout the book, defined words are printed in bold the first time they appear. The bold font signals that a definition of this term can be found in the online glossary on the website.
- A limited number of suggested books for Further Reading are listed at the end of each chapter in the printed book. A more extensive Further Reading list is available on the Companion Website as an annotated bibliography with additional books, articles, and links to websites, listed by chapter.
- The printed book provides questions for review and discussion at the end of each chapter. Additional exercises with end-of-chapter questions, activities, and projects are available on the Companion Website.
- Case studies and white papers on the Companion Website examine additional topics and specific skills.
- Educators can find presentation slides to accompany lectures for each chapter on the Companion Website.

Abbreviations

A	ampere (amp)
AASHE	Association for the Advancement of Sustainability in Higher Education
AC	alternating current
AEES	advanced ecologically engineered system
APC	American Plastics Council
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
B-100	100 percent biodiesel
B-2	2 percent biodiesel
BAN	Basel Action Network
BART	Bay Area Rapid Transit
BAT	best available technique
bbl	blue barrel
BCE	before common era
Bcf	billion cubic feet
BECCS	Bioenergy with Carbon Dioxide Capture and Storage
BEV	battery electric vehicle
BHAG	big, hairy, audacious goal
BMP	best management practice
BOD	biochemical oxygen demand
BP	before present
BPA	bisphenol A
BREEAM	Building Research Establishment Environmental Assessment Method
BRICS	Brazil, Russia, India, China, and South Africa
BRT	bus rapid transit
Bt	*Bacillus thuringiensis*
Btu	British thermal units
C2C	Cradle to Cradle (certification)^{CM}
C&D	construction and demolition
CAFO	concentrated animal feeding operation
CCOF	California Certified Organic Farmers
CCS	carbon capture and sequestration
CDR	carbon dioxide removal
CE	common era

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbon
CFL	compact fluorescent light
cfm	cubic feet per minute
CH_4	methane
CHP	combined heat and power
CII	commercial, institutional, industrial
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COPR	Canada Organic Product Regulation
CPTED	crime prevention through environmental design
CRZ	critical root zone
CSA	community-supported agriculture; Canadian Standards Association
CSD	Commission on Sustainable Development
CSO	Combined sewer overflow
CVP	Central Valley Project
DACCS	Direct Air Carbon Dioxide Capture and Storage
DC	direct current
DDT	dichloro-diphenyl-trichloroethane
DFD	design for disassembly
DFE	Design for the Environment
DMS	dimethyl sulphide
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DoD	Department of Defense
E10	10 percent ethanol
E85	85 percent ethanol
EC	European Commission
EIA	Energy Information Administration
EMS	environmental management system
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 1992
EROEI	energy returned on energy invested
ESA	Endangered Species Act
ESCO	energy services company
ESY	Edible Schoolyard
EU	European Union
EUI	energy utilization index
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FERC	Federal Energy Regulatory Commission
FFTH	Food From the 'Hood
FLO	Fairtrade International

FSC	Forest Stewardship Council
FWS	Fish and Wildlife Service
GATT	General Agreement on Tariffs and Trade
GBI	Green Building Initiative
GDP	gross domestic product
GM	genetically modified
GMO	genetically modified organism
gpf	gallons per flush
GPI	Genuine Progress Indicator
gpl	gallons per load
gpm	gallons per minute
GPRC	Great Plains Restoration Council
GRAS	Generally Recognized As Safe
GRI	Global Reporting Initiative
GW	gigawatt
GWP	global warming potential
H_2O	water
HAP	hazardous air pollutant
HBN	Healthy Building Network
HCP	habitat conservation plan
HDPE	high-density polyethylene
HFC	hydrofluorocarbon
HID	high-intensity discharge
HRS	Hazard Ranking System
HVAC	heating, ventilating and air conditioning
ICI	institutional, commercial, industrial
ICPD	International Conference on Population and Development
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
IPMVP	International Performance Measurement and Verification Protocol
IPPC	Integrated Pollution Prevention and Control
IPPUC	Urban Planning Institute of Curitiba
ISEW	Index of Sustainable Economic Welfare
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature and Natural Resources
KAB	Keep America Beautiful
kW	kilowatt
kWh	kilowatt-hour
LCA	life cycle assessment (or analysis)
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LEED AP	LEED Accredited Professional
LEED GA	LEED Green Associate

LEED-ND	LEED for Neighborhood Development
LID	low-impact development
LTL	less than a load
M&V	measurement and verification
Mcf	thousand cubic feet
MDG	Millennium Development Goal
MHCHS	Mole Hill Community Housing Society
MRF	material recovery facility
MRL	maximum residue limit
MSC	Marine Stewardship Council
MSW	municipal solid waste
MW	megawatt
N_2	nitrogen
N_2O	nitrous oxide
NAPL	nonaqueous phase liquid
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NGO	nongovernmental organization
NMFS	National Marine Fisheries Service
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
NPO	non-product output
NRC	National Recycling Coalition
NREL	National Renewable Energy Laboratory
NSF	National Sanitation Foundation
O_2	oxygen
O_3	ozone
O&M	operations and maintenance
OECD	Organization for Economic Cooperation and Development
OTEC	ocean thermal energy conversion
OWC	oscillating water column
P2	Pollution prevention
PBT	persistent, bioaccumulative, and toxic
PCB	polychlorinated biphenyl
PBDE	polybrominated diphenyl ether
PEFC	Programme for the Endorsement of Forestry Certification
PHEV	plug-in hybrid electric vehicle
$PM_{2.5}$	particulate matter less than or equal to 2.5 micrometers in diameter
PM_{10}	particulate matter less than or equal to 10 micrometers in diameter
POP	persistent organic pollutant
ppb	parts per billion
ppm	parts per million

PPP	Polluter Pays Principle
psi	pounds per square inch
PURPA	Public Utility Regulatory Policies Act of 1978
PV	photovoltaic
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
REC	renewable energy certificate (or credit)
RNA	ribonucleic acid
ROI	return on investment
R-value	resistance to heat flow
SCP	sustainable consumption and production
SCS	Scientific Certification Systems; Soil Conservation Service
SER	Society for Ecological Restoration
SES	social-ecological systems
SES	Soil Erosion Service
SETAC	Society for Environmental Chemistry and Toxicology
SFI	Sustainable Forestry Initiative
SHGC	solar heat gain coefficient
SITES	Sustainable Sites Initiative
SO_2	sulfur dioxide
SOx	sulfur oxides
SPI	Society of Plastics Industries
SRM	solar radiation modification
STARS	Sustainability Tracking, Assessment & Rating System
STRAW	Students and Teachers Restoring a Watershed
SUV	sport-utility vehicle
TBL	triple bottom line
Tcf	trillion cubic feet
TDM	transportation demand management
TDML	total daily maximum load
TDS	total dissolved solids
TFR	total fertility rate
TOD	transit-oriented development
TSCA	Toxic Substances Control Act
TSDF	treatment, storage, and disposal facility
TSE	Truck Stop Electrification
TSS	total suspended solids
UGB	urban growth boundary
UN	United Nations
UNEP	United Nations Environment Programme
US	United States
USDA	US Department of Agriculture
USGBC	US Green Building Council
USGS	US Geological Society
U-value	heat transfer coefficient
V	volt
V2G	vehicle-to-grid

VICS	Voluntary Interindustry Commerce Solutions Association
VMT	vehicle miles traveled
VOC	volatile organic compound
VT	visible transmittance
WASCO	water service company
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WHO	World Health Organization
WRI	World Resources Institute
WTE	waste-to-energy
WTO	World Trade Organization
WWF	World Wildlife Fund

Part 1

Context

1 What is sustainability?

We live in a vast, three-dimensional, interconnected web of energy flows and life forms. Years ago our world appeared to be the size of whatever culture we lived within and felt as if it were stable and unchangeable. Our world is now understood to be planetary in scale, to be changing very fast, and to be situated either at the threshold of a planetary disaster of unprecedented magnitude or at the beginning of a sustainable new era. Whatever the outcome, the new state of the world will not be like it is today.

In this world of planet-scale crises and opportunities, sustainability is a topic of increasing focus. Many people are familiar with some of the strategies employed in sustainability efforts: solar panels, recycling, or harvesting rainwater, for example. These are important positive steps. They and many others are discussed in more detail later in the book, but by themselves they cannot make the current conditions sustainable. So, what does it mean to be sustainable?

Defining sustainability

Sustainability means enduring into the long-term future; it refers to systems and processes that are able to operate and persist on their own over long periods of time. The adjective “sustainable” means “able to continue without interruption” or “able to endure without failing.”[1] The word “sustainability” comes from the Latin verb *sustinēre,* “to maintain, sustain, support, endure,” made from the roots *sub,* “up from below,” and *tenēre,* “to hold.” The German equivalent, *Nachhaltigkeit*, first appeared in the 1713 forestry book *Sylvicultura Oeconomica* written by Hans Carl von Carlowitz, a mining administrator in a region whose mining and metallurgy industry depended upon timber and who realized that deforestation could cause the local economy to collapse. Carlowitz described how through sustainable management of this renewable resource, forests could supply timber indefinitely.

We are part of linked systems of humans and nature, so the study of sustainability goes beyond environmentalism. A key attribute of the field is a recognition of three interrelated dimensions: ecological, economic, and social. The planet faces many problems that are connected, including poverty, impaired health, overpopulation, resource depletion, food and water scarcity, political instability, and the destruction of the life support systems on which we all depend. Scholars debate about whether environmental destruction causes poverty, or whether poverty causes environmental destruction out of sheer desperation, but it is agreed that they go together (Caradonna 2014, 224). We cannot fix one problem in isolation because they are all connected.

The three dimensions of ecological sustainability, economic opportunity, and social inclusion are captured in the phrase **sustainable development**. The term was introduced in *World Conservation Strategy,* a 1980 report by the International Union for Conservation of Nature (IUCN) and the first international document to use the term (ibid. 141). It was made popular in the 1987 report *Our Common Future,* produced by the World Commission on Environment and Development (WCED) and commonly known as the Brundtland report, which highlights the connection between environment, economics, and equity. Gro Brundtland wrote that "the environment is where we all live; and 'development' is what we all do in attempting to improve our lot within that abode. The two are inseparable" (WCED 1987, 7). In the Brundtland report, "sustainable development" is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (ibid. 43). Sustainable development recognizes the rights of all people, including future generations, to grow and flourish.

These three dimensions—environment, economics, and equity—are sometimes called the "**triple bottom line**" (TBL), a term introduced in 1997 by corporate responsibility expert John Elkington (Elkington 1998, 70). They are sometimes referred to as the "three Es" and are also known as the three pillars of sustainability or "planet, people, and prosperity" (United Nations 2015b, 3).

Sustainability science is a field of study devoted to tackling the challenges of sustainable development in the transition toward sustainability. This field is interdisciplinary, "defined by the problems it addresses rather than by the disciplines it employs" (Kates 2010, 26). Its work integrates research on stabilizing the human population, reducing hunger and poverty, sustaining the life support systems on which we all depend, and the interactions among these systems. Sustainability science focuses on understanding the dynamics of these coupled ecological and social systems (Vries 2013, 5).

Systems thinking

The study of sustainability is the study of systems. A **system** is a coherently organized set of interconnected elements that constitute a whole (Meadows 2008, 188), where the identity of the whole is always more than the sum of its parts. The properties of the whole cannot be predicted by examining the parts; they are **emergent** properties, arising from the relationships and interactions of the parts. Systems are nested within other systems. A cell, an organ, and a human body are all systems, as are an ecosystem, an ocean, and an economy. The Earth itself is a system, made of myriad other nested and interconnected systems; it is the focus of a field of study known as Earth system science.

The field known as systems science became part of the public conversation in 1972 with the publication of the groundbreaking *Limits to Growth*, the result of a study by MIT systems scientists Donella and Dennis Meadows and Jorgen Randers commissioned by a think tank called The Club of Rome. The report included the first modern use of the word "sustainable" (Caradonna 2014, 138). Using cutting edge computer models, the researchers analyzed in detail how economic growth, consumption, and population growth would cause humans to exceed the limits of Earth's **carrying capacity** and lead to a condition of **overshoot**.

Carrying capacity is the maximum number of individuals a given environment can support indefinitely. Its inverse is the **ecological footprint**, the demand placed on nature for resources consumed and wastes absorbed, expressed as land area. Earth is currently operating at 140 percent of its capacity (Ewing et al. 2010, 18) and on track to be operating at 200 percent by the 2030s (Gilding 2011, 52). That is, we are already in overshoot: the condition in which human demands exceed the regenerative capacities of the biosphere. Ecological economist Herman Daly identified four conditions for avoiding overshoot: In order to live sustainably within Earth's carrying capacity, humans would need to maintain the health of ecosystems (our life-support systems); use renewable resources at a rate no faster than they can be regenerated; use nonrenewable resources at a rate no faster than they can be replaced by the discovery of renewable substitutes; and emit wastes and pollutants at a rate no faster than the rate at which they can be safely assimilated (Daly 1990).

Humans have overshot Earth's carrying capacity and are living by depleting its **natural capital** and overfilling its waste sinks (Rees 2014, 192). Natural capital consists of the resources and services provided by the Earth system (Matson et al. 2016, 32). Renewable resources can support human activities indefinitely as long as we do not use them more rapidly than they can regenerate. This is analogous to living off the interest in a savings account and not spending the capital. We have the planetary equivalent of a savings account, but it is made of plants, animals, soil, water, and air (Hawken et al. 2008). This natural capital provides **ecosystem services**, the biological functions that support life, including provision of materials and food, assimilation of wastes, seed dispersal, pollination, nutrient recycling, purification of air and water, and climate regulation.

Resilience

Much sustainability work focuses on the concept of **resilience**. Resilience science originated in the field of ecology and is based on the understanding that life is not static, that change is inevitable. "At the heart of resilience thinking is a very simple notion—things change" (Walker and Salt 2006, 9). Resilience is the capacity of a system to accommodate disturbance and still retain its basic function and structure (ibid. xiii); it is the capacity to cope with change. A resilient system adapts to changes without losing its essential qualities. All systems which are resilient share common traits: they are self-organizing and they feature diversity, modularity, and connectivity.

Whether in ecosystems, such as forests or oceans, or in social systems, such as cities or nations, the more diverse a system is and the more variations there are, the better that system will be able to deal with change and stay resilient. Diversity gives a system flexibility; it has multiple ways to perform its functions, so the failure of one part does not cause the entire system to crash (Mazur 2013, 355). The parts of a resilient system are connected, although not in a predictable, linear way (Walker and Salt 2017, 165).

In social and ecological systems, modularity means that groups of parts are strongly connected internally, but only loosely connected to other groups.[2] When one module fails, others keep functioning and the larger system has a chance to self-organize (Walker and Salt 2006, 121). For example, a local food system is a module that may also be connected with national and global food sources, but when there is a disruption in the larger distribution chain, people in the community can keep growing food and are less likely to go hungry.

Connectivity is a feature of all resilient systems. Familiar examples include cells connected within organisms, organisms connected within ecosystems, habitat patches connected by wildlife corridors, nonprofit groups connected across the internet, and global climate systems connected by biogeochemical cycles. Connections between parts of a system are what allow the system to self-organize and adapt.

We understand that humans and ecosystems are not separate, but are interdependent and dynamically linked. In resilience and sustainability science these integrated systems are known as social-ecological systems: linked systems of humans and nature (Walker and Salt 2012, 1). Social-ecological systems are **complex adaptive systems** (CAS).

Sustainability and resilience are not synonymous but are interrelated concepts. They provide complementary frameworks that are employed toward the same goal: to enable social-ecological systems to continue into the long-term future. A sustainability approach identifies long-term goals, examines strategies for achieving those goals, and systematically evaluates using indicators. A resilience approach emphasizes change as a normal condition, recognizes that a system may exist in multiple stable states, and focuses on building adaptive capacity to respond to unexpected shocks and disturbance. Sustainability scholar, Charles Redman explains it this way: "sustainability prioritizes outcomes; resilience prioritizes process" (Redman 2014, 37).

Complex adaptive systems

The problems facing the planet, such as climate change, mass extinction, water scarcity, and poverty, are challenging because they are intrinsically systems problems (Meadows 2008, 4). Systems are complex.[3] Complexity refers to systems that have outcomes which are indeterminate and cannot be predicted (Ehrenfeld 2008, 100); their behavior is nonlinear (Heinberg and Lerch 2010, 31; Wessels 2006, 120). The many systems which make up the larger Earth system are known as complex adaptive systems. Their elements are interconnected. It is not possible to change one component of a complex adaptive system without affecting other parts of the system, often in unpredictable ways.

Complex adaptive systems are self-organizing systems. They use connections and **feedbacks** to regulate their behavior and keep it within certain boundaries so that the system retains its basic function and structure: that is, it is resilient. Feedback is a circular mechanism in which change in one part of a system triggers changes in the other part of the system that in turn loops back to influence the initial process. A positive feedback loop increases or amplifies the original change; for example, a warming climate is melting Arctic sea ice, exposing darker colored water which absorbs more sunlight, which warms the air and causes more sea ice to melt. A negative feedback loop decreases or dampens the original change; for example, a warmer temperature could potentially increase the amount of cloud cover and block incoming sunlight (NOAA 2014). Negative feedback loops tend to maintain the status quo; positive feedback loops tend to propel change (Lenton 2016, 7).

Complex adaptive systems feature emergent behavior. **Emergence** is the spontaneous appearance of novel properties at the level of a system that cannot be predicted by knowledge of the system's parts. Emergent properties arise from interactions among parts of a system, and are always more than the sum of the parts (Vries 2013, 547). Resilience arises from the interactions of the parts of the system, and in fact, resilience is an emergent property of complex systems (Walker and Salt 2017, 164).

No system can be understood at a single scale. Every system is composed of subsystems and is nested within a larger system, all of them operating over a range of spatial scales and time scales, with each scale going through its own adaptive cycle (ibid., 174). Scientists, designers, and planners look at larger and smaller scales, above and below the system they are studying because self-organizing systems and subsystems are linked across a range of scales. This nested hierarchy of adaptive cycles at multiple scales in a social-ecological system is referred to as panarchy, from Greek words that mean “ruling over everything” (Rees 2010b, 33).

Tipping points

Complex adaptive systems feature emergent behavior. This means that not only are they inherently unpredictable, but they can have more than one stable state (Walker and Salt 2006, 36). Systems have critical thresholds, sometimes referred to as tipping points, at which seemingly small changes cause a system to shift abruptly and irreversibly into a new state (OECD 2012, 26).

A ball in a basin is a metaphor from the field of resilience science that illustrates multiple stable states and thresholds in a system (Figure 1.1). The ball tends to roll

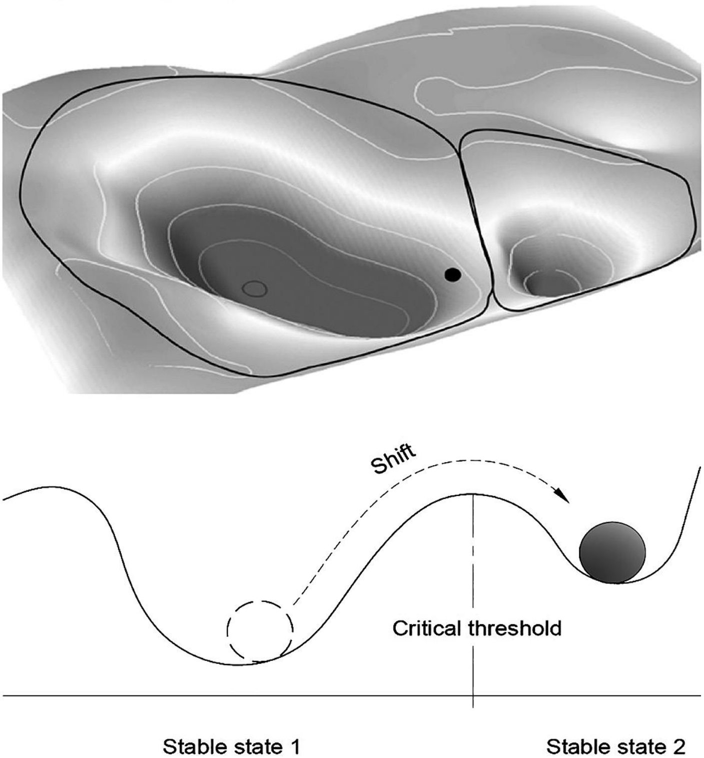

Figure 1.1 The system as a ball in a basin.

Top image source: Deborah O’Connell, Brian Walker, Nick Abel, and Nicky Grigg. *The Resilience, Adaptation and Transformation Assessment Framework: From Theory to Application*. CSIRO, Australia: 2015.

Bottom image source: author diagram.

toward the bottom of a basin, that is, toward a state of equilibrium. The shape of a basin and the position of the ball change constantly as external conditions change (Walker and Salt 2006, 54). When the state of a system (the ball) is near a threshold, even a small push can move it into a new regime (a basin). Once a system crosses a threshold into a new domain, its identity changes. The new domain is a new stable state, and the change is often irreversible.

Examples of state change include the collapse of the Atlantic cod fishery due to overfishing, prolonged drought leading to desertification, land subsidence[4] caused by over-pumping of groundwater, rioting that brings down a government, or people caught in a poverty trap of declining capital with a growing population in a degraded landscape.

These state shifts can be planetary in scale and can be difficult to predict; changes accumulate incrementally and the actual threshold is usually not known in advance (Barnosky et al 2012, 52). One potential tipping point is global temperature, where a small increase in average temperature may trigger abrupt, large-scale, and irreversible changes in the global climate system (AAAS Climate Science Panel 2014, 15; IPCC 2018, 254).

Living in the Anthropocene

Geologists divide time on Earth into segments based on physical characteristics of geology, climate, and life.[5] The Holocene was the 10,000-year epoch spanning all of written human history until now, a time between ice ages with a warm and unusually stable climate which allowed civilization to develop. These extraordinarily stable conditions made it possible for population to expand, agriculture to appear, and human cultures to arise and flourish (Wijkman and Rockström 2012, 38). We live at the beginning of a new geological epoch known as the **Anthropocene**, a time in which human activity has become such a powerful force that it has major, planet-scale impact on climate and on every living system. Geologists are working to formalize the geological unit as an official designation and to determine what physical evidence should be used as its marker (Anthropocene Working Group 2019).[6]

In 2009, a group of scientists undertook a collaborative research effort to define the crucial processes and global boundary conditions which could ensure that the planet remains in a stable, Holocene-like state, a “safe operating space” within which human society could continue to develop (Wijkman and Rockström 2012, 44). Researchers defined planetary boundaries for nine interdependent areas of the global commons: climate change, biodiversity loss, excess nitrogen and phosphorus production, stratospheric ozone depletion, ocean acidification, freshwater consumption, land-use change, air pollution, and chemical pollution; they mapped these onto a radial graph with one wedge for each area of concern and with boundaries denoted by concentric rings (Figure 1.2). The concept of planetary boundaries and their graphic illustration was a powerful way to communicate complex scientific issues to a broad lay audience (Folke 2013, 29). The researchers found that humanity has already exceeded the safe boundaries for the first three: climate change, biodiversity loss, and nitrogen production (Rockström et al. 2009a; 2009b). As is typical of complex systems, the planetary boundaries are interconnected, so that crossing one boundary may shift the positions or critical thresholds of other boundaries

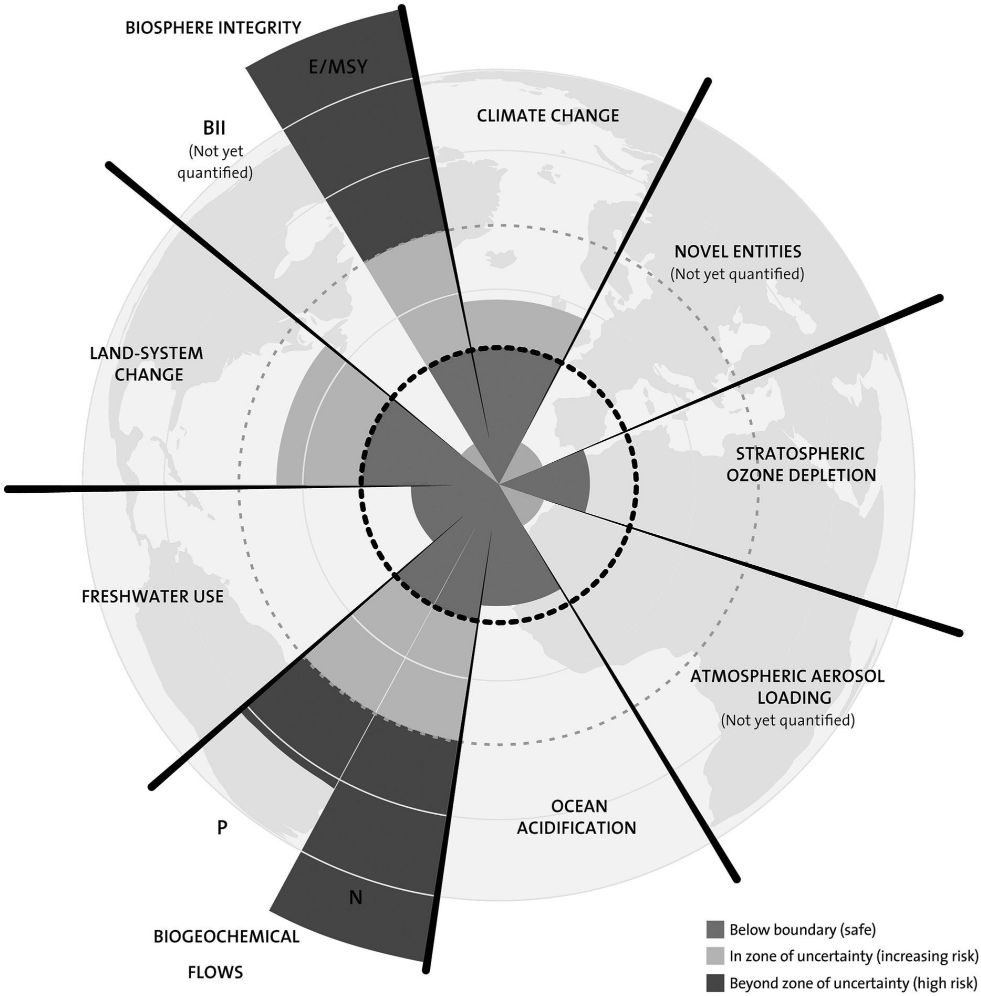

Figure 1.2 Planetary boundaries.

Source: Azote Images/Stockholm Resilience Centre.

(Folke 2013, 26). While scientists debate the precise setting of particular boundaries, there is general agreement on the fundamental concept that there are limits to the safe functioning of the Earth system (Lenton 2016, 115).

We face multiple, global-scale issues including food scarcity, aquifer depletion, pollution, habitat destruction, extinction, depletion of renewable and nonrenewable resources, climate destabilization, social inequity, failing states, growing control by powerful corporate interests, and widening gaps between rich and poor. A mass extinction is underway, with species disappearing at 1000 times the normal rate (Primack 2008, 126). Storms and wildfires are growing, mountain glaciers are melting, sea level is rising, and indications are that we may be approaching a climate-system tipping point. Many of these issues are what are known as wicked problems, problems that are difficult to solve because they are complex, interconnected, and continually evolving (Steffen 2014, 1). Behind them all lie two fundamental drivers: consumption, built on the economic growth model, and human population growth.

Humans have gone through several major transitions in their history: the discovery of fire, the development of language, the development of agriculture and civilization, and the Industrial Revolution. Today we live on the threshold of what has been called the "fifth great turning" (Heinberg 2011, 284), a turn away from a fossil fuel-powered, climate-destabilizing, growth-based industrial economy and toward a sustainable, regenerative society.

We live in a new geological epoch, the Anthropocene. The Holocene has come to an end, and humanity faces novel conditions it has not encountered before. The question is not whether we will change, but how, and what form the transition will take. Navigating the shifting conditions, fostering the fifth great turning in the sociocultural realm while we strive to avoid crossing planetary-scale thresholds into an undesirable state shift in the biospheric realm, will require that we find ways to live better and to work together like never before. We will need to shift rapidly away from fossil fuels, power our lives with renewable energy sources, use energy more efficiently whatever the source, reduce per-capita resource consumption, provision ourselves from zero-waste circular economies, reduce population growth, provide food to increasing numbers of people without converting new areas of land or destroying habitat, protect biodiversity, protect ecosystem services, and generally live within the planet's capacity to support us and our fellow creatures into the long-term future. We will need to define what is meant by "sustainability," use those definitions to measure and monitor trends so that we can assess where we are moving toward or away from sustainability, and develop evidence-based strategies with the potential for real, measurable progress (Engelman 2013, 13). We will need not just technological adaptations, but social and political ones as well. Sustainability will depend on having informed, ecologically literate citizens working toward healthy ecosystems, genuine social inclusion, and equitable distribution of resources. We will need strong communities, networks of all kinds, and participatory governance at multiple scales, as we build the foundations for a thriving, sustainable human civilization and biosphere (ibid., 17).

Notes

1. American Sign Language (ASL) Interpreters have a variety of ways to sign "sustainability." One sign could be voiced (or translated) as "continuing on." Another combines the signs for "inherit, pass from generation to generation" plus "can" (Thornton 2019).
2. In product design, modularity is a pattern of repeated components which are interchangeable.
3. In systems science, "complex" does not simply mean "more complicated." The word "complicated" (from the Latin verb *complicare,* to fold together) refers to a system with many parts where there are knowable causes and effects and one can predict the outcomes given enough information. For example, a jet engine is a complicated system. "Complex" (from the Latin verb *complectere,* to braid or to entwine around) refers to a nonlinear system in which interactions are emergent and outcomes cannot be predicted. For example, the Amazon rainforest is a complex system.
4. Land subsidence is a sinking of the Earth's surface.

5. Geological time is subdivided into hierarchical segments. From the largest to the smallest division, the terms are eon, era, period, epoch, and age.
6. The Anthropocene is discussed in more detail at the end of the next chapter.

Further reading

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Meadows, Donella, Jorgen Randers, and Dennis Meadows. *Limits to Growth: The 30-Year Update*. White River Junction, VT: Chelsea Green, 2004.

Thiele, Leslie Paul. *Sustainability*, 2nd ed. Cambridge, UK: Polity, 2016.

Worldwide Institute. *State of the World 2013: Is Sustainability Still Possible?* Washington, DC: Island Press, 2013.

Critical thinking and discussion

1 An elevator speech is a concise summary that can be conveyed within the span of a 30-second elevator trip. If a neighbor learned you were studying sustainability and asked, “So, what is sustainability?” what would you say? Write an “elevator speech” to explain the basic concepts of sustainability.

2 An elevator speech gives you a period of time, albeit short, to describe a concept. But what about situations where you are called upon to give an even shorter, concentrated summary? If you were in a checkout line at a market, you mentioned to the clerk that you were studying sustainability, and the clerk said to you, “Sustainability? What is that?,” what would you say? Write one to two concise sentences that give a quick, comprehensible overview, understandable by someone for whom the subject is unfamiliar.

3 Think about a sustainability issue the planet faces, one with which you are familiar. Does the knowledge needed for finding solutions come from one academic discipline, or more than one? List the disciplines you think might be involved in addressing this issue.

4 Our species has had an extraordinary impact on the biosphere. Why do you think that is?

5 Modern society is experiencing rapid innovation and change. Do you think the rate of change is a sign of unsustainability or progress? Is there a simple answer?

6 Do you think that laws and regulations are necessary in order to move society toward a sustainable future?

7 Two common diagrams for representing sustainability use simple circles. The triple bottom line of sustainability is traditionally illustrated by three intersecting circles representing environment, economics, and social equity. Some scholars prefer to illustrate the triple bottom line of sustainability with concentric circles by placing the economic and social spheres within the circle representing environment. What messages does each version convey? What do they say about the

relationships between ecology, economics, and equity? Once you have answered, can you think of a different possible message each version could represent?

8 People sometimes feel overwhelmed by the magnitude of the problems our planet faces. If you were working on a sustainability project and someone told you, "There is no point in trying to be sustainable, since it is hopeless anyway," how would you respond?

9 Are the terms "sustainability" and "sustainable development" interchangeable? If not, how do they differ?

10 Imagine a community of bacteria living on a Petri dish. A single bacterium was placed on the dish at midnight. Their population doubled once an hour. At 1:00 a.m. there were 2 bacteria, by 2:00 a.m. there were 4 bacteria, and so forth. At noon, 12 hours later, their food supply ran out. At what time of day was half their food used up?

2 A brief history of sustainability

Sustainability is a multidisciplinary field that encompasses the entire planet, its constituents, and inhabitants as a whole. Earth's planetary system has until recently maintained a state of dynamic equilibrium—it has been sustainable—since its beginnings approximately 4.5 billion years ago. So the history of sustainability as a concept, the state of being sustainable, could in one view encompass the entire long and interwoven story of our planet. Telling the life story of our planet involves most of the science disciplines including atmospheric science, geology, chemistry, and biology.

Sustainability as a concept is also about the human role within the biophysical world, and the history of sustainability includes examination of how humans have related to the rest of nature through time. The study of human relationships to the natural world through time is a field of study called **environmental history**.

Understanding the past helps us plan for the future. The global social-ecological system that has evolved during the Holocene exhibits complex webs of interconnections and emergent properties that are characteristic of complex adaptive systems. Thus the future cannot be predicted. But understanding how humans and the rest of nature have interacted over time can help us to clarify the options for creating a more sustainable future (Costanza et al. 2007, 522).

Recent history: the last 200 years

In general, Western culture has maintained a belief that economic growth and ever-improving standards of living can continue forever. However, a few influential books which suggested that some human activities might not be sustainable began to appear in the last 200 years or so.

Beginning in 1798 Thomas Malthus, a British scholar in the fields of political science and economics, wrote six editions of his influential treatise, *An Essay on the Principle of Population.* He wrote: "The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race" (Malthus [1798] 2008: 61). This work predicted that population growth was inevitable and that it would continue until it outstripped the resources available. Malthus said that population was expanding at geometrical rates while food supplies were increasing at only arithmetical rates. He argued that in any society, population would continue to increase until it reached the carrying capacity of its resources, when various natural controls—disease, famine, or war—would cause ecological and social collapse, reducing the numbers again. This process is known as the Malthusian cycle (Christian 2011, 312).

Henry David Thoreau was one of the first Americans to question the belief that nature and its resources were inexhaustible (Nash 1988, 36). He was a careful observer, and he noticed that wild species were beginning to disappear from his region in Massachusetts. In an effort to understand nature better, he built a cabin in the woods on Walden Pond where he lived alone for two years, observing and writing. Foreshadowing the science of ecology, Thoreau saw nature as an interconnected community. In *Life in the Woods*, he wrote: "What we call wildness is a civilization other than our own" (ibid.).

In 1864 George Perkins Marsh, a United States (US) diplomat and historian, published *Man and Nature; Or, Physical Geography as Modified by Human Action*, a description of the destructive impacts of human civilization on the environment. Marsh used scientific reasoning to show how the rise and fall of past civilizations were connected to overuse of resources. He suggested that stewardship of the planet was more than an economic issue, that it was an ethical issue (ibid.).

John Muir was a naturalist who spent several years exploring the North American wilderness from Alaska to California. His journal entries were published in several books which became popular. Muir championed the idea of national parks as a way to save vanishing wilderness and was largely responsible for establishing Yosemite National Park in 1890. Two years later, in 1892, he founded the Sierra Club. He was a proponent of the idea that nature has intrinsic value independent of its usefulness to humans (Thiele 2013, 17).

The connection between greenhouse gases and climate change began to appear in the nineteenth century when Irish physicist John Tyndall demonstrated that gases including carbon dioxide, methane, and water vapor could absorb and re-emit radiation (Zalasiewicz et al. 2019, 6). In 1908, the Swedish chemist Svante Arrhenius calculated that emissions from the burning of coal was making the planet warmer and would lead to global climate change (IPCC 2007a, 105), although he thought that a warmer climate would prevent occurrence of another ice age and would stimulate plant growth allowing humans to grow more food to feed a growing population (Zalasiewicz et al. 2019, 6). Warnings about global climate change would surface again in the mid-1970s, this time from the international scientific community.

Early conservation

In the late nineteenth century, nonhuman animals were killed in great numbers for sport. By the end of the century, large areas of southern Africa were nearly emptied of the game, and hunting for ivory had devastated elephant populations.

A number of wildlife conservation organizations were established in Britain in the late nineteenth and early twentieth centuries. In Africa, lands were set aside for wildlife but conservation was often based on a hunting ethos, and hunting was denied to African inhabitants but not to Europeans (Frontani 2015). In these early years, "white men hunted; Africans poached" (Adams 2008, 31).

During the nineteenth century, nonhuman animals were also killed in great numbers for fashion. US congressman John Lacey, alarmed at the slaughter of birds for the purpose of decorating women's hats, sponsored the Lacey Act of 1900 which made the interstate transport of illegally-killed wildlife a federal offense. England, Germany, and the Netherlands also saw campaigns against the use of wild-bird feathers for hat decoration (Koppen and Markham 2008, 265), with a movement in Germany led by the influential German League for Bird Protection. This early thinking about the rights of other species to life and habitat later developed into endangered species legislation (Nash 1988, 49). The Lacey Act helped some birds but not all and in 1914, following years of decimation from hunters, the last passenger pigeon died in captivity at the Cincinnati Zoo.

Theodore Roosevelt, US Republican president from 1901 to 1909, was a passionate conservationist. In 1903, shortly after passage of the Lacey Act, he established the first National Wildlife Refuge at Pelican Island in Florida for the protection of endangered brown pelicans. A few years later he used a new law, the Antiquities Act, to protect the Grand Canyon and other areas that became national parks, set aside federal lands as national monuments, and added vast tracts of land to the system of federal forest reserves (Miller et al. 2009, S34).

In the first half of the twentieth century, many scientists and policymakers saw nature as a resource to be managed for the benefit of humans. Gifford Pinchot, a name often associated with this view, was appointed the first chief of the newly-formed US Forest Service in 1905. In contrast to people such as John Muir, who argued for preserving wilderness in its untouched state, Pinchot believed that forests were in essence a kind of crop and that public forest lands should be managed scientifically (Merchant 2007, 143).

Transformation from conservation to ecology

Scientific understanding of the living world underwent a transformation in the twentieth century. **Conservation** and the view of nature as a resource to be efficiently managed had tended to look at each crop or element in isolation. The science of **ecology**, which appeared in the nineteenth century in Europe and the US and flowered in the twentieth century, studied not objects but relationships and connections in the larger environment (Edwards 2005, 12). The word ecology comes from the Greek word *oikos*, meaning "household." German biologist Ernst Haeckel began using the term "ecology" in his books and articles in the 1860s (Merchant 2007, 180). He wrote that biologists had overlooked "the relations of the organism to the environment, the place each organism takes in the household of nature, in the economy of all nature" (ibid.).

The concept of the food web and food pyramid, outlined by zoologist Charles Elton in 1927, helped to put the human position in the natural world into a different perspective. Elton presented the feeding relationships in nature as a pyramid, with a few predators at the top and very large numbers of plants and bacteria at the bottom. If the predator at the top of the food pyramid—the human—is removed, the system is hardly affected. But take away plants or bacteria at the base, and the pyramid collapses. The food pyramid revealed that humans are far from indispensable and in fact are vulnerable. Elton also developed the concept of ecological niches, finely-tuned functional roles within the structure of an ecosystem (Nash 1988, 57).

Frederic Clements was a central figure in the emerging field of ecology known for his theories about ecological **succession** in plant communities, a process that he believed led to the stable equilibrium of **climax** vegetation (Merchant 2007, 182). The view he laid out in his 1916 book *Plant Succession* is called the organismic approach to ecology because for him a plant community was like a complex living organism. Other scientists in the organismic school of ecology developed the idea that cooperation among individuals in a community was at least as important as competition and the old Darwinian idea of “survival of the fittest.”

An economic approach to ecology developed as a kind of alternative to organismic ecology. British ecologist Arthur Tansley first introduced the term **ecosystem** in a 1935 paper. Tansley had studied thermodynamics and applied terms from that field, including “energy” and “systems,” to the field of ecology. A few years later, in 1942, ecologist Raymond Lindeman re-introduced the concept of the “food chain” or **trophic levels** (ibid., 186–87). “Trophic” refers to nutrition. In the food chain, food is metabolized at each trophic level, and in metabolizing, each plant or animal converts energy from the trophic level below it.

The chemist Ellen Swallow developed the concept of human ecology, an approach in which humans are not separate from nature or managers of nature; they are part of nature and work within it. This branch of ecology was expanded during the 1960s by ecologist Eugene Odum, who argued that the economic approach that works for maximizing productivity of ecosystems can lead to degraded ecosystems. He proposed applying science and ethical principles to repair damaged ecosystems. Odum’s perception of the Earth as a network of interconnected ecosystems was one of the guiding principles in the environmental movement that emerged in the 1960s (ibid., 186–89).

Chaos theory and complexity theory, a branch of mathematics that developed in the 1970s and 1980s, influenced the study of ecology. In their 1985 book *The Ecology of Natural Disturbance and Patch Dynamics*, ecologists S. T. A. Pickett and P. S. White described ecosystems as dynamic rather than the homogeneous stable systems of successional climax communities. The idea of a stable balance of nature had implied that humans were capable of repairing degraded ecosystems, that it was in effect just a matter of getting the mechanics right. Complexity and chaos theory meant acknowledging that while nature does have patterns that can be recognized, nature is unpredictable; it is not only more complex than we know, it is more than we *can* know. We can work in partnership with nature but can never master it.

The beginnings of the environmental movement

What we think of as sustainability as a field of study got its start with the environmental movement in the 1960s and 1970s. Books, conferences, and college classes on environmental topics first began to appear in the early 1970s. The movement was heralded by the publication of Rachel Carson’s book *Silent Spring* in 1962. The book, which documented the destructive effects of pesticides on the environment, was widely read and became a best seller.

Rachel Carson was a biologist with the US Fish and Wildlife Service (FWS) at a time in American history when the old DuPont advertising slogan, “Better Things for Better Living … through Chemistry,” expressed the spirit of the age. World War II had propelled the growth of the petrochemical industry, resulting in an explosive proliferation of varieties of plastics, chemical compounds, and synthetic pesticides. One of the most popular chemical pesticides was dichloro-diphenyl-trichloroethane (DDT), widely used on crops, forest lands, roadsides, and residential lawns across the country. Technology was seen as a positive tool for progress, although the appearance of dead birds on front lawns began to raise questions for some people.

The title of Carson's book, *Silent Spring*, was a reference to a world without birds that could be the ultimate outcome of indiscriminate pesticide use. As a scientist, Carson researched her book meticulously and grounded it in rigorous science. She made a forceful case for the severe damage that reckless spraying of pesticides had inflicted on wildlife and exposed the potential threat to humans as well. She did it with an eloquent, poetic writing style that made the subject accessible to ordinary people. Up to that time, technology had been seen as the realm of scientists and government regulators, and Americans generally entrusted it to the experts who appeared to understand the complicated details of biology and chemistry. Carson pulled back the curtains and allowed ordinary citizens to see into the world of the experts. *Silent Spring* encouraged citizens to become informed and to become actively engaged, and in so doing helped usher in the spirit of participatory democracy that characterized the 1960s (Magoc 2006, 227).

The Population Bomb, published by biologist Paul Ehrlich in 1968, was another influential best seller in the 1960s that raised awareness of environmental issues. This book, too, raised the level of understanding about technical topics for ordinary citizens. *The Population Bomb* illustrated exponential growth for lay readers, presented existing data about population, and let people see what would happen if these patterns continued (Merchant 2007, 195). *The Population Bomb* had been presaged in 1948 by the influential best seller *Road to Survival* by ecologist William Vogt, who showed that declining resources and overpopulation were trends that were connected.

The environmental awareness raised by Rachel Carson and others, underscored by telling events such as a 1952 fire on the Cuyahoga River in Ohio,[1] culminated in the first Earth Day on April 22, 1970. First suggested by US Senator Gaylord Nelson of Wisconsin and organized by Harvard graduate student Denis Hayes, Earth Day was billed as an "Environmental Teach-In." New York City shut down Fifth Avenue for the event, thousands of colleges and universities organized rallies, and 20 million people participated in cities across the country. Some historians see Earth Day as the beginning of the modern environmental movement in the US (ibid., 199).

Topics of alternative energy and appropriate technology entered the public awareness in the 1970s. In 1973 conflict in the Middle East led to an Arab oil embargo and a fuel shortage known as the "oil crisis." While the energy crisis lasted only a few months, it spurred public interest in both energy conservation and the search for alternatives to fossil fuels.

At the same time as the energy crisis, in 1973, British economist E. F. Schumacher published *Small Is Beautiful: Economics as if People Mattered.* The book was an early introduction to the idea that perpetual economic growth is not sustainable. It suggested that human well-being was a more appropriate measure of progress than was a gross national product and it encouraged people to think about the connections between environmental, social, and economic health. It also introduced the concept that nonrenewable natural resources such as fossil fuels should be treated as capital, not as expendable income. It encouraged people to consider appropriate use of technology and the value of small, local economics. The book became another bestseller.

In 1972, a groundbreaking report, *Limits to Growth,* raised awareness of the Earth's physical limits to growth: the planet's ability to provide materials and energy and to absorb waste and pollution. An international team of researchers at MIT fed data on five social-ecological factors and their interactions into computer models, then tested their behavior under several sets of assumptions to develop possible future trajectories. These detailed scenarios showed that if present trends continued, limits to Earth's carrying capacity would be reached within the next 100 years, leading to overshoot and collapse (Lenton 2016, 111). The report also described how altering those trends could result in a transition to a sustainable system (Meadows et al. 2004, 234).

The 1970s began with Earth Day and continued to be years of activism and participation. New environmental organizations including Worldwatch Institute, Greenpeace, and the Natural Resources Defense Council were founded. The battle over a community named Love Canal in the US put environmental threats from hazardous waste in the public spotlight and made them personal: toxins were not just things that affected other species and distant places; they could affect you in your own home. It also showed how ordinary citizens could be effective agents for change.

Love Canal was a pleasant community near the iconic Niagara Falls whose homes and schools were built on the former waste site of a chemical company. As mothers of school children talked to each other they discovered an unexpected and alarming pattern of miscarriages, birth defects, and childhood cancer. One of the mothers, Lois Gibbs, organized a community group whose members educated themselves about hazardous waste and put pressure on the state and on the federal government. In 1978 President Carter declared a State of Emergency. The Love Canal disaster led to the passage of legislation in 1980 that became known as Superfund, establishing a system for identifying and cleaning up hazardous waste sites. Gibbs, whose two children had both experienced serious health problems as a result of living at Love Canal, devoted her life to the antitoxics movement. She organized the Citizens' Clearinghouse for Hazardous Wastes, a coalition of community groups headquartered in Washington, DC. She also founded a magazine called *Everyone's Backyard* aimed at helping local groups move beyond the "NIMBY" (Not in My Backyard) phenomenon to what she called Not in Anyone's Backyard (Magoc 2006, 250–52).

Political responses

US environmental legislation in the 1970s

The public awareness that was awakened by Rachel Carson's *Silent Spring* and that bloomed on the first Earth Day was part of a process that led to a series of legislative moves for the protection of the environment. The 1970s was an extraordinary decade for environmental law (Lazarus 2004, 67–75).

The year 1970 began with the National Environmental Policy Act (NEPA) being signed into law by President Nixon on January 1 with great fanfare. Called the "Magna Carta of environmental law" by many commentators (ibid., 68), NEPA was established "to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic and other requirements of present and future generations of Americans." The year ended with an executive order from President Nixon that reorganized the Executive Branch to create the Environmental Protection Agency (EPA), a federal agency charged with administering environmental laws enacted by Congress.

A string of sweeping legislation followed NEPA, beginning with the Clean Air Act in 1970. The Clean Air Act required the EPA to publish a list of hazardous air pollutants, set emissions standards, and achieve reductions at specified levels. It also required the EPA to review the scientific bases for air quality standards every five years and to include an adequate margin of safety to protect the public health.

The Water Pollution Control Act of 1972 was an amendment to an earlier act. It required that all navigable waters in the US be "fishable and swimmable" by 1983 and prohibited all discharge of pollutants into navigable waters without a permit by 1985. The Act also regulated the potential filling of wetlands. The 1974 Safe Drinking Water Act established standards for contaminants in public water supplies. Like the other environmental laws of the 1970s, the Act passed overwhelmingly in the House and the Senate with bipartisan consensus. One legislator, Senator Cotton, later commented: "After all, if one votes against safe drinking water, it is like voting against home and mother" (Lazarus 2004, 69). Protection of water expanded in 1977 with the Clean Water Act.

Energy conservation was promoted by the Energy Policy and Conservation Act of 1975. Two years later the US Department of Energy was created. The National Energy Act of 1978 was a response to the 1973 energy crisis and included tax credit incentives for the development of renewable clean energy sources, although they were eliminated a few years later.

In 1972 the use of DDT was banned and the Federal Pesticide Control Act, an amendment of the earlier Insecticide, Fungicide, and Rodenticide Act, was passed. The Toxic Substances Control Act (TSCA) was passed in 1976; it regulated manufacture, sale, use, and disposal to prevent "unreasonable risk of injury to health or the environment." The Resource Conservation and Recovery Act (RCRA), also passed in 1976, regulated the generation, transportation, treatment, storage, and disposal of hazardous wastes "as necessary to protect human health and the environment."

A number of other acts were revisions of older natural resource laws. Earlier laws, with their roots in the nineteenth century, had focused on using and exploiting natural resources. The new laws focused on conservation and preservation.

Perhaps the most far-reaching legislation was the Endangered Species Act (ESA) of 1973. This landmark law was groundbreaking in at least two ways: it gave legal protection to the rights of at least some nonhumans and it adopted an ecosystem approach to environmental protection. Its primary goal was to prevent the extinction of species imperiled as a "consequence of economic growth and development untempered by adequate concern and conservation" (*Endangered Species Act of 1973*, 16 US Code 1531 et seq.). It protected species and "the ecosystems upon which they depend." The ESA is administered by the US FWS and the National Oceanic and Atmospheric Administration (NOAA), which includes the National Marine Fisheries Service (NMFS). In addition to preventing extinction, the ESA is also intended to help **threatened** or **endangered** species recover. Once a species has gone through a **listing** process and has been listed as threatened or endangered, FWS and NMFS are required to create a detailed recovery plan. A 1978 amendment to the ESA noted that the goal of the law is to make itself unnecessary, and recovery plans are a means toward that goal. Existence of this law has not prevented species from going extinct at an accelerating rate, both in the US and worldwide.

The transformation of the legal landscape during the 1970s was not limited to the federal government. New federal laws gave substantial roles for implementation to states. For example, under the Clean Water Act states were to develop their own permitting programs, which meant that they were responsible for overseeing compliance with the federal water pollution control law. The other federal environmental laws gave the states similar roles.

European environmental legislation in the 1970s

The 1970s saw a dramatic rise of the environmental movement in Europe. As in the US, there was widespread public concern about air and water pollution, population growth, and resource depletion. The post-World War II period of the 1950s and 1960s had been a time of economic rebirth in Europe and continued industrial expansion in North America. The burgeoning economic growth not only intensified existing environmental threats; it generated new threats. At the same time, newly created wealth gave individuals and governments the financial resources to pursue quality of life goals, beyond basic survival needs (Long 2000, 9). All of this created favorable conditions for a broad environmental movement.

An oil spill off the southwest coast of England in 1967 from the supertanker *Torrey Canyon*, the world's worst oil spill at the time, was a disastrous example of pollution. A massive oil slick fouled hundreds of miles of British and French coastlines. Cleanup attempts with toxic, solvent-based emulsifiers killed large numbers of seabirds and aquatic animals and caused extensive environmental damage. The navy tried to burn away the oil by dropping bombs, then aviation fuel, then Napalm, to set fire to the ocean (Barkham 2010).

In 1968, water in Swedish lakes—and lakes elsewhere in Europe—became so acidic that fish began dying. It was clear that acidification could not be attributed to Swedish emissions, and that the acid rain falling on the lakes must have come from air pollution in countries of the UK and Central and Eastern Europe. The problem of acid rain illustrated the transboundary nature of pollution (Jordan and Adelle 2012, 14). Transboundary issues, particularly air pollution and shared water resources, became dominant concerns at the first United Nations (UN) Conference on the Human Environment in Stockholm in 1972.

The Stockholm conference was a seminal event. A number of countries around the world created environmental agencies and ministries following the 1972 Stockholm conference.[2] Following the conference, the European Council declared the need for environmental policy, and by the next year began issuing Environment Action Programmes to guide environmental policy goals and legislation.

The Organization for Economic Cooperation and Development (OECD) is a group of democratic governments who came together in the post-World War II period to promote cooperation and seek solutions to common problems.[3] In the mid-1960s, members began bringing their governments' environmental concerns to the OECD, and in response to a growing global concern over environmental issues, the OECD established an Environment Committee and then the OECD Environment Directorate in 1971. Following the UN Stockholm conference, in 1972 the OECD adopted the Polluter Pays Principle (PPP) as a guiding principle. Three years later, PPP was adopted by the European Community.

Countries within the EU and OECD have developed individual robust programs as well. The German government introduced an environmental program in 1971, and the German Environment Agency (*Umweltbundesamt*, or UBA) was founded in 1974.[4] The UBA is Germany's main environmental protection agency, responsible for detecting and addressing risks from land, air, and water pollution. The UBA conducts its own research, oversees research by scientific institutions in Germany and elsewhere, and is responsible for implementing environmental law in Germany, which now includes climate change and carbon dioxide trading. Some of the principles that underlie EU environmental policy have their roots in German principles and law (McCormick 2001, 84).

Environmental awareness and activism were also emerging in France during this time. The 1967 *Torrey Canyon* oil spill had damaged the coast of Brittany, a 1968 translation of Rachel Carson's *Silent Spring* was popular, and in 1969 a nationwide campaign was launched to save the alpine Vanoise national park from development as a ski resort, with a massive letter-writing campaign from activists and scientists. President Georges Pompidou responding by rescinding the development's approval and then creating the Ministry of the Environment[5], elevating the ministry above an agency level to a body with cabinet-level authority. The ministry, which began operation in 1971, brought together a broad range of issues and functions from diverse existing agencies under a single concept, "the environment." Director Robert Poujade noted that the word "environment," by its very essence, "brought out countless connections among people and things" (Bess 2003, 84), reflecting an emerging understanding of ecology and systems thinking.

In 1952, the same year the Cuyahoga River caught fire in the US, soot over the skies of London led to the deaths of 4000 inhabitants (Long 2000, 9). Four years later, the UK enacted the first Clean Air Act. In 1970, it created a Department of Environment with a cabinet position, the Secretary of State for the Environment. Restructuring occurred later, and in 1996, the Environment Agency was formed in the UK by an Act of Parliament. One of its first projects was restoration of the Thames River. The Thames, once informally known as the "Great Stink," had carried sewage and chemical wastes from laundries that operated along its banks in the nineteenth century, killing most of the fish and other aquatic life. By 1957, the Thames had been declared biologically dead. The new Environment Agency began regulating water quality and wastewater treatment, and by 2015 the Zoological Society of London declared that the Thames now supported fish as well as seals and porpoises (Saxer and Rosenbloom 2018, 169). The Environment Agency is responsible for protecting and enhancing the environment in England. It operates under the jurisdiction of the UK's Department for Environment, Food and Rural Affairs (DEFRA).

The European Union (EU), a political and economic union of 27 member states in Europe, was built on a series of treaties beginning in 1957, with the EU itself formally established in 1993 (Jordan and Adelle 2012, 3). The environmental protection agency for the EU, formed the same year, is the European Environment Agency (EEA). It includes the EU member states and six additional states. The European Commission is the executive branch of the EU; it proposes new environmental policy and law, implements and enforces legislation from the European Parliament. The Parliament plays a major role in shaping EU environmental law.

The EU now has some of the highest environmental standards in the world. EU environmental policy from the outset has rested on several key principles including the precautionary principle, the "polluter pays" principle, addressing pollution at its source, and sustainable development. EU policy says that the EU will be climate neutral by 2050.

Environmental justice

Growing awareness of the dangers of pesticides and other hazardous chemicals beginning in the 1960s led to one of the key attributes of the field of study we now call sustainability: the triple bottom line of environment, economics, and equity (Edwards 2005, 21).

One arena for concerns about equity was the labor union movement. Efforts to organize farm workers laboring in the fields of California began in 1962, the year *Silent Spring* was published. Cesar Chavez and Dolores Huerta, co-founders of the drive to organize the United Farm Workers of America, made protection from pesticide exposure for farm workers a top priority (Magoc 2006, 232). They and other union organizers insisted that only a union contract could guarantee protection for workers. Through their work, as well as the work of Rachel Carson, increasing numbers of people began to realize that the goals of a safe and healthy workplace and the goals of a healthy environment were intertwined. People also began to realize that the old dependence on trusting the experts was not enough and that citizen participation was essential.

Another arena was the civil rights movement. In 1982 a disposal site for polychlorinated biphenyls (PCBs), a toxic chemical used as a coolant in electrical transformers and as an additive in many industrial compounds, was proposed for a Warren County, North Carolina neighborhood that was primarily African American. Protests began immediately. Residents and civil rights organizers joined together to block roads and stage rallies that raised awareness about the dumping of toxic chemicals in minority neighborhoods.

One of the protest leaders in Warren County was the civil rights activist Ben Chavis. He coined the phrase "environmental racism" to describe the proposed Warren County dump site. In 1987 Chavis authored a report for the United Church of Christ's Commission on Racial Justice, "Toxic Wastes and Race in the United States." His report, which located hazardous waste sites by zip code, showed that almost every major city in the country located its hazardous waste sites in areas whose residents were members of minority communities. The report helped to spark a nationwide **environmental justice** movement (Merchant 2007, 202).

Environmental ethics

Growing awareness of social and environmental concepts, including the interconnectedness of life, led to increased interest in the moral relationship between humans and the rest of the natural world (Brennan and Lo 2015). Philosophers, scholars, activists, and citizens began to ask questions about the rights of nature. The result was the development in the early 1970s of a modern branch of philosophy known as environmental ethics, a field which considers whether only humans are morally considerable, or whether moral standing should extend to other species or even to ecosystems; whether non-human species and larger systems have intrinsic value or only instrumental value; and whether humans are part of nature or separate (McShane 2009, 407; Rolston 2012, 517).

Intrinsic value is the assumption that a thing has value in itself, regardless of its usefulness for humans. Instrumental value is the assumption that a thing is valuable insofar as it benefits humans (Kopnina and Shoreman-Ouimet 2015). Some early conservationists, such as Gifford Pinchot, believed that the human species had intrinsic value, while non-human species and systems had only instrumental value. Others, including Henry David Thoreau, John Muir, and Aldo Leopold, saw the interconnectedness of all life and believed that all elements of the biosphere had intrinsic value (Brennan and Lo 2015). Most environmental ethics thinkers ascribe intrinsic value not only to human beings but to entities other than humans.

Discussions of animal rights formed an early element in an emerging environmental ethic. In the seventeenth century, French philosopher René Descartes had asserted that animals had no moral standing because, he thought, they were not sentient and had no ability to feel pleasure or pain, but by the late eighteenth century, this view was changing. British philosopher Jeremy Bentham had argued that skin color should not be a basis for treating some humans differently than others. In 1789 he extended the logic, arguing that number of legs or whether one has fur or a tail should not be a basis for mistreatment, writing about animals in an often-quoted statement, "The question is not, Can they *reason* nor, Can they *talk*? but, Can they *suffer?"* (Nash 1988, 23). Nineteenth-century philosophers including John Stuart Mill and Henry S. Salt continued to advance the thinking on animal rights. In 1975 philosopher Peter Singer published *Animal Liberation,* a book which vividly brought issues of animal rights into the awareness of the general public and which became popular with readers outside the academic world. Referring to the dismissal of animals' rights as speciesism, Singer and philosopher Tom Regan became influential voices for the rights of non-human animals. In the academic world the ethics of animal rights, or what Singer called animal liberation, was sometimes criticized by other scholars because it was utilitarian,[6] an approach that typically ascribes intrinsic value only to sentient beings but not plants or landscapes, and because it was individualistic, that is, ascribing intrinsic value to individuals only but not to ecological wholes such as ecosystems (Brennan and Lo 2015).

Valuing ecological wholes was at the core of an idea known as the land ethic. Aldo Leopold was an ecologist, conservationist, philosopher, and author whose lyrical essays had a powerful influence on how people thought about nature. His most famous work, *A Sand County Almanac,* originally published in 1949, became a bestseller during the flowering of environmental awareness in the 1970s. Its culminating chapter, "The Land Ethic," expanded the moral sphere from humans to animals to the land itself (Leopold 1987). Beginning his essay with a dramatic story about Odysseus' hanging of his slave girls, Leopold laid out parallels between human slavery and human approaches to land as merely a commodity.

Leopold described an ethical sequence in which the "extension of ethics" from individual to society to land itself "is actually a process in ecological evolution" (Leopold 1987, 202). He saw the possibility that ethics was a social instinct which was evolving in human society (Callicott 1991, 15). Some scholars agree, noting that superorganisms, including humans and some insects, have developed various social restraints for regulating behavior. Ethics is one method; social insects such as ants and termites use other methods (Callicott 1989, 65). Membership in a community confers evolutionary advantages for survival.

Leopold said that "[e]thics are possibly a kind of community instinct in-the-making" (Leopold 1987, 203). With the land ethic, he expanded what constitutes a community beyond individuals to other animals, plants, soil, and water as a collective whole. He stressed the importance of the integrity of the biotic community and saw humans as members of that larger community. In one of his most well-known statements in the closing section of "The Land Ethic" he wrote, "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise" (ibid., 224).

This underscores a theme running throughout both environmental ethics and sustainability generally: the nature of the distinctions between parts versus wholes or individuals versus communities, a notion considered in more detail in the next chapter. Philosopher J. Baird Callicott wrote of them all as "nested communities" (Light and Rolston 2003, 26). Philosopher Holmes Rolston III noted that what we perceive as individual competition, such as the relationship between cougar and deer, may be cooperation when viewed from another scale (Rolston 1989, 250). He described individuals as close-coupled systems and communities as weak- or loose-coupled systems, "though not less valued," pointing out that "[a]dmiring concentrated unity and stumbling over environmental looseness is like valuing mountains and despising valleys" (ibid., 253). Rolston said thinking that ecosystems do not count morally because they lack sentience or a sense of self "makes another category mistake. To look at one level for what is appropriate at another faults *communities* as though they ought to be organismic *individuals*" (ibid., 255).

Legal scholars look for ways to codify environmental ethics into law. One arena is animal rights law. For example, a team of animal law attorneys at the Animal Legal Defense Fund works to protect animals from abuse by filing civil lawsuits on their behalf. Legal scholar Steven M. Wise teaches animal rights law at several US law schools; he and other attorneys from the Nonhuman Rights Project[7] argue in the courts for the rights of animals including, as a starting point, legal personhood for certain nonhuman primates (Wise 2000).

In 1972, law professor Christopher Stone argued for the legal rights of trees and other natural objects in a groundbreaking essay, "Should Trees have Standing?" Stone constructed the legal argument for a case being heard before the US Supreme Court, *Sierra Club v. Morton*. The Sierra Club was fighting a massive development in Mineral King Valley in the Sierra Nevada Mountains; a US Court of Appeals had ruled that the Sierra Club did not have legal standing, and the case was being reviewed by the Supreme Court. Stone took up the question in his famous essay, published in the *Southern California Law Review,* which he sent to Justice William O. Douglas. Although the Court majority ruled against the Sierra Club, three justices ruled in its favor. Justice Douglas wrote an impassioned dissenting opinion, citing Stone's argument on the first page of his opinion and concluding with a reference to Leopold's "Land Ethic" (Stone 1972, 73-84). Although the Sierra Club did lose its appeal to speak for the valley, the cost of years of delays convinced Walt Disney Enterprises to abandon the development, and a few years later the US Congress added the valley to Sequoia National Park.

Some governments "are expanding fundamental rights to the planet itself" (Assadourian 2013, 120). In 2008, Ecuador declared that nature has the "right to exist, persist, maintain and regenerate its vital cycles, structure, functions and its processes in evolution." Four years later, a court in New Zealand declared the Whanganui River to be a legal entity, "an integrated living whole," with a legal voice under New Zealand law. The river was granted legal status, thanks to years-long efforts by the local Māori people, the Whanganui iwi. Under the ruling, two guardians will protect the Whanganui River's interests, one appointed by the iwi and one by the Crown (Postel 2017, 238).

Intrinsic value was codified in Bolivian law in 2011, which defined 11 "Rights of Mother Earth" including "the right to life and to exist; the right to continue vital cycles and processes free from human alteration; the right to pure water and clean air; the right to balance; the right not to be polluted; and the right to not have cellular structure modified or genetically altered" (Moore and Nelson 2013, 230).

The concept of ethics within the work of sustainability also concerns, of course, the rights of all humans to survive and thrive. Environmental justice works to address environmental inequalities, particularly among low-income people and people of color impacted by toxic pollution and unfair land use patterns. Intergenerational equity concerns the rights of people not yet born and our obligations to them. Social equity, generally, involves equal access to resources for all people, equal opportunity to participate, and efforts on behalf of the rights of humans who are less able to speak in their own defense: people who live in poverty, in conditions of power imbalance, and at the bleeding edge of climate change impacts.

Expanding to a global scale

Our perspectives on issues of sustainability have expanded. *Silent Spring*, Love Canal, and environmental racism focused on issues that were, in some ways, local. Meanwhile our view has opened up also to encompass a global dimension. The expanding perspective may have started with "Earthrise."

In 1968, Paul Ehrlich published *The Population Bomb*, protests over the Vietnam War raged in the streets, and the Apollo 8 mission sent astronauts around the moon. On December 24 the astronauts entered the lunar orbit planning to take photos of the moon's surface. They looked up to see the Earth rising over the moon's horizon; amazed, they grabbed a camera and took an unplanned picture (Poole 2010, 1). When the photograph of "Earthrise" reached Earth in a live broadcast, people saw a tiny blue and white planet floating in the black void of space. The impact of that image was significant. People began to use the term "spaceship Earth" as a reminder that this world on which we live is finite and the only home we have. Galen Rowell, a photographer for *Life* and *National Geographic* magazines, called Earthrise "the most influential environmental photograph ever taken" (Hosein 2012).

An even more dramatic photograph was sent back to Earth by the crew of Apollo 17 on their way to the moon in 1972. The sun was behind them, the Earth was fully illuminated, and this time the camera captured the entire planet floating in blackness. The crew dubbed the photograph the "Blue Marble." The picture captured people's imaginations during a surge in environmental awareness (Miller 2009, S35). DDT had just been banned, a series of environmental laws had just been passed, and memories of the first Earth Day were still fresh. The "Blue Marble" vividly reinforced, in an immediate and inescapable way, the vulnerability and isolation of the planet in the vast expanse of space. These two photographs, "Earthrise" and "Blue Marble," enabled ordinary people to conceive of their world on an unprecedentedly global scale.[8]

The same year as the Apollo 17 flight the UN, a union of countries worldwide that by definition is global in scope, organized the first-ever global environment summit, the 1972 UN Conference on the Human Environment, in Stockholm, Sweden. This meeting was where ideas about sustainable development were first discussed as part of an international agenda. When the prime minister of India, Indira Gandhi, spoke to the assembly, she said, "Are not poverty and need the greatest polluters? How can we speak to those who live in villages and in slums about keeping the oceans, the rivers, and the air clean when their own lives are contaminated at the source? The environment cannot be improved in conditions of poverty" (Adams 2008, 61). The UN commissioned economist Barbara Ward and microbiologist René Dubos to prepare a report, *Only One Earth*, to guide the conference discussions (Ward and Dubos 1972). Dubos is credited with coining the phrase "think globally, act locally" which became popular a few years later (Mackenbach 2006, 575; Evans 2012, 84).

In advance of the summit, 30 leading scientists signed a work titled *Blueprint for Survival.* Released as the January 1972 issue of the journal *The Ecologist*, and soon after published as a widely read book, the text presented technical details about ecosystems and their disruption, social systems and their disruption, population and food supply, and nonrenewable resources. It emphasized not just environmental problems but the overwhelming need for "change towards a stable and sustainable society," setting out steps that would be needed to build a "stable and sustainable society" (Goldsmith 1974, 25). The UN Conference on the Human Environment that followed attempted to connect environmental concerns and economic issues (Smil 2002, 22). One of the results was the establishment of the United Nations Environment Programme (UNEP), whose mission was to "provide leadership and encourage partnerships in caring for the environment by inspiring, informing and enabling nations and people to improve their quality of life without compromising that of future generations" (Edwards 2005, 15). Global leaders were beginning to recognize the importance of including all three pillars of sustainability.

More global-scale efforts followed. The Worldwatch Institute was founded by Lester Brown in 1973 to measure worldwide progress toward sustainability; in his 1980 sustainability roadmap *Building a Sustainable Society,* Brown defined a sustainable society as "one that is able to satisfy its needs without diminishing the chance of future generations" (Brown 1981). The term "sustainable development" was first used in the 1980 report, *World Conservation Strategy: Living Resource Conservation for Sustainable Development*, by the IUCN, commissioned by UNEP. In 1983, the UN created the World Commission on Environment and Development (WCED), headed by Gro Harlem Brundtland, former prime minister of Norway. The Commission was asked to set out shared definitions and goals, propose long-term strategies for sustainable development, and recommend ways to address environmental and economic concerns through international cooperation. The Commission's 1987 report *Our Common Future*, often called "the Brundtland report," adopted Brown's phrase in what has become the most often quoted definition of sustainability: it said that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, 43).

The Worldwatch Institute released its first annual *State of the World* report in 1984. The report made a clear connection between economic development and the environment. An overview chapter observed, "We are living beyond our means, largely by borrowing against the future" (Edwards 2005, 17).

Attention to climate change on a global scale began to coalesce. In the 1970s the international scientific community had begun issuing the first modern warnings of global climate change caused by the buildup of greenhouse gases from human activity. In 1983 the US EPA and the National Academy of Sciences published reports connecting the buildup of greenhouse gases and rising temperatures (Miller 2009, S37). By 1988 the UNEP acknowledged the magnitude of the issue and, together with the World Meteorological Organization, established the Intergovernmental Panel on Climate Change (IPCC). The IPCC assesses and synthesizes published peer-reviewed scientific research, producing reports considered by most governments and international organizations to be authoritative (Blockstein and Wiegman 2010, 9).

In 1992 the UN organized the United Nations Conference on Environment and Development, known as the Earth Summit, in Rio de Janeiro, Brazil. Delegates from 180 countries agreed to a set of 27 principles in the Rio Declaration on Environment and Development, often called simply the Rio Declaration. They adopted Agenda 21, a "comprehensive blueprint for a global partnership [that] strives to reconcile the twin requirements of a high-quality environment and a healthy economy for all people of the world" (UN 1992; Sitarz 1994).[9] They generated the UN Convention on Biological Diversity, a legally-binding international treaty. They also generated the UN Framework Convention on Climate Change, a nonbinding treaty that later led to the creation of the **Kyoto Protocol**.

Many of the agreements made at the Rio Earth Summit have not been realized. In 1997, the UN General Assembly held a special session called Earth Summit+5 to evaluate progress on implementing Agenda 21. Their report found progress was uneven and identified trends including widening economic inequalities and continued deterioration of the global environment. In 2002, the UN organized the World Summit on Sustainable Development in Johannesburg, South Africa, known as the Earth Summit 2002, boycotted by the US, at which delegates reaffirmed their commitment to Agenda 21 and a new set of goals known as the Millennium Development Goals (Evans 2012, 89).

In 2000, members of the UN ushered in the new millennium at a special Millennium Conference, where they adopted a set of goals aimed at halving extreme poverty in all its forms, including hunger, illiteracy, and disease, by 2015 (Sachs 2015, 144). The agreement was called the Millennium Declaration and it established a set of 8 Millennium Development Goals (MDGs), coordinated by the United Nations Development Programme: (1) Eradicate extreme poverty and hunger. (2) Achieve universal primary education. (3) Promote gender equality and empower women. (4) Reduce child mortality. (5) Improve maternal health. (6) Combat HIV/AIDs, malaria, and other diseases. (7) Ensure environmental sustainability. (8) Develop a global partnership for development. The goals were not met by 2015. However, they did draw the world's attention to the challenges of extreme poverty, generate new partnerships, and mobilize global efforts. As a result, the number of people living in extreme poverty declined by more than half, the percentage of undernourished people in developing countries fell by almost half, the number of 5- to 11-year-old children not in school fell by almost half, and the death rate for children under 5 fell by more than half (United Nations 2015a, 4).

In 2001 the UN initiated the first of a series of reports called the Millennium Ecosystem Assessment. This report synthesized the work of over 1,360 scientists and other experts from around the world to present measurable indicators of the condition of "Earth's natural capital" (Millennium Ecosystem Assessment 2005). Its prognosis was not encouraging. The report concluded that it was still possible to reverse much of the degradation of the planet's ecosystems over the next 50 years, but "the changes in policy and practice required are substantial and not currently underway."

Still, joining together to face and resolve an environmental crisis that is global in scope is possible. Evidence for that can be seen in the story of the thinning ozone layer that became a global problem in the 1980s. **Chlorofluorocarbon** (CFC) had originally been introduced in the 1930s as an improvement, a more benign substance to replace the use of toxic ammonia, methyl chloride, and sulfur dioxide as refrigerants. In 1976, however, a report from the US National Academy of Sciences reported that CFCs were causing the thinning of the protective stratospheric ozone layer that shields the earth from excessive ultraviolet rays. In 1985, 20 nations signed the Vienna Convention for the Protection of the Ozone Layer. That same year, dramatic seasonal thinning was discovered in the ozone layer above Antarctica. It became known in the popular press as the "ozone hole" and increased public attention to the issue. In a 1987 multinational agreement called the Montreal Protocol, signed by 43 countries including the US, the industrial world agreed to phase out CFCs and to stop producing them altogether by 1996 (Evans 2012, 83). Some 196 nations have signed subsequent revisions of the Protocol; scientists predict that at the current rate the ozone layer will recover by 2050.

Progress in addressing the threat of global climate change has not been so encouraging. Although awareness of climate change is broad, the causes and potential solutions are more complex. CFCs were produced by only a small number of corporations, primarily DuPont, and their production was concentrated in the industrialized nations (ibid.). Greenhouse gases that lead to climate change, particularly carbon dioxide and methane, are produced by humans in every nation and are connected and augmented through feedback loops and other global-scale, complex mechanisms.

The UN Conference on Sustainable Development, often referred to as Rio+20, was held in Rio de Janeiro, Brazil in 2012. Its outcome document, *The Future We Want*, laid out a common vision including a concise description of principles of sustainable development (United Nations 2012, 2). The agreement surveyed the results of UN declarations and conventions from the previous 40 years and laid the plan for a new set of sustainable development goals to carry forward the work of the MDGs (ibid., 46).

Over the next two years, working groups and stakeholders developed a system of 17 goals with 169 measurable targets and indicators known as the Sustainable Development Goals (SDGs). There are many goals and targets because, rather than being written by a few specialists, they were developed by stakeholders from both developed and developing countries and agreed upon by consensus. In 2015, world leaders at the United Nations Sustainable Development Summit adopted the SDGs, which aim to end poverty and hunger, fight inequality and injustice, support economic progress for all people, sustainably manage freshwater resources, restore terrestrial and marine ecosystems, address climate change, and make cities and human settlements inclusive, safe, resilient, and sustainable by 2030, to be accomplished through partnerships, participation, and good governance.

Modern trends

By the mid-1980s, sustainability activists were seeing a need for alternatives to large-scale projects. An anti-environmental backlash in the US in the 1980s had weakened some of the legal controls for environmental protection (Merchant 2007, 199). The early promises of the Rio Earth Summit had not materialized. Wars continued to threaten stability worldwide. The threats of pollution, declining biodiversity, and increasing global temperature seemed daunting. One possible response could have been to feel helpless in the face of the immensity of these challenges and to give up. But many activists decided that the thing to do was to focus on what they could do within their individual spheres of influence. Bumper stickers with the slogan "think globally, act locally" began to appear. **Bioregionalism** and **place-based learning** programs were introduced in schools and universities (Orr 1992, 73; Plant et al. 2008, 8). Local food programs developed. Since the 1980s the numbers of sustainability organizations, programs, and initiatives have increased dramatically, with an explosion in the numbers of community organizations both in physical locales and in internet communities.

The 1990s and 2000s were lively years in the field of sustainability as the number of sustainability-related organizations increased dramatically and sustainability became firmly established within schools, colleges, and universities. Professionals moved beyond simply recognizing that problems existed to developing ways of measuring both problems and progress. New closed-loop approaches to product design and manufacturing appeared. Architects and builders took up the challenge of sustainability and increasingly sought to get their projects certified by organizations such as the US Green Building Council.

Scholars within higher education have taken an active role in shaping the sustainability movement. The first US college to offer a major in Environmental Studies was Middlebury College, in 1965. The US green-campus movement got its start in 1987 when David Orr of Oberlin College set up quantified studies of the use of energy, water, and materials on several college campuses. Today, hundreds of colleges and universities offer degrees in environmental studies, environmental science, and sustainability. Sustainability has taken an increasingly important position in primary and secondary education as well. Beginning in Europe, sustainability science became a recognized academic discipline.

As sustainability began to mature into an established subject, measurable data became important. In the early 1990s, two scholars at the University of British Columbia developed the idea of measuring human impact and comparing it with the biophysical world's carrying capacity, calling this approach the ecological footprint. Another set of data-driven tools, sustainability indicator reports, have become standard components of sustainability programs for many companies and institutions.

A related approach called life cycle analysis or **life cycle assessment** (LCA) was developed around the same time as ecological footprint tools (Giudice et al. 2006, 87). This accounting process, now used by some manufacturing companies and many architects, measures the environmental impacts of a material or thing from cradle to grave. In the 1990s American architect William McDonough and German chemist Michael Braungart recognized that something was still missing, and in 2002 published their seminal book *Cradle to Cradle: Remaking the Way We Make Things*. Their approach suggested that we imitate nature's systems, where the concept of waste does not exist and where byproducts from one cycle become nutrients for another.

Data are only useful when they are reliable, and so the practice of formal certification, with verification by independent third parties, became an accepted element of sustainability practice. Beginning in the 1990s and 2000s, certification processes were developed for a range of areas that included greenhouse gas reporting, organic food, green buildings, products and materials, and fair labor practices.

Into the Anthropocene

We live at the dawning of a new geological epoch, the Anthropocene, an unprecedented period in which human activity has become the primary driver of physical planetary change. The recent geological epoch has been formally known as the Holocene, a period of warm and extraordinarily stable climate conditions between ice ages that was ideal for the development of human civilization.[10] Research indicates that without negative human impacts, the ideal conditions of the Holocene would probably continue for several thousand years more (Wijkman and Rockström 2012, 40).

The term "Anthropocene," from the Greek words *anthropo,* "human," and *–cene,* from *kainos,* "new" or "recent," was proposed in 2000 by atmospheric chemist Paul Crutzen and biologist Eugene Stoermer. Each time period, such as an epoch, leaves behind a physical, "stratigraphic signature" that will still be visible in the geological record millions of years from now (Kolbert 2014, 109). The International Commission on Stratigraphy (ICS) is the official body which formally establishes the geological time scale; in 2019, the Anthropocene Working Group within the ICS[11] determined that a new epoch should be officially designated and is now working to determine what physical evidence should be used as its marker (Zalasiewicz 2019, 269). Candidates include carbon and oxygen isotopes; fly ash particles; industrial glass microspheres; large changes in carbon, nitrogen, phosphorus, and other geochemical cycles; extensive artificial ground around cities; and abrupt changes in species ranges, such as so-called invasive species (ibid., 286).

When Crutzen and Stoermer began to define the Anthropocene, the epoch was generally understood to have begun around 1800 CE at the start of the Industrial Revolution (Crutzen 2002, 23). But its discernible impacts on atmospheric chemistry and biogeochemical cycles began to appear much later, in the mid-twentieth century.

Beginning in 1945, the Anthropocene entered a second stage researchers identify as the "Great Acceleration" (Figure 2.1), when multiple aspects of human impact including population, resource use and environmental deterioration began expanding exponentially (Steffen, Crutzen, and McNeill 2007, 617). Graphs of each of these impacts reveal a similar curve, with a shape often compared to the blade of a hockey stick.

The Great Acceleration will result in a distinct stratigraphic boundary beginning around 1950 that will remain visible in the geological record. In 2019, the Anthropocene Working Group voted (with an 88 percent majority) that the Anthropocene should be treated as a formal geological epoch and that the base of the epoch should begin with stratigraphic signals of the mid-twentieth century (Anthropocene Working Group 2019).

Humans have become a geological force on a planetary scale. One way to address the enormous challenges that confront us is to identify the global boundaries within which it is safe to operate for each of several interrelated systems: the preconditions of a stable, Holocene-like state (Folke 2013, 22). This was the framework of the collaborative research effort on planetary boundaries, first published in an influential 2009 article in *Nature,* "A Safe Operating Space for Humanity" (Rockström et al. 2009a), which was discussed in the previous chapter.

Sustainability as a movement began as many small, quiet revolutions. In countless corners of the world, it has gradually coalesced—from small pockets of awareness and grassroots action, from legislation and global cooperation, from innovative designers, from the work of leaders, scholars, and educators. The future shape of the field is still forming, but it seems clear that sustainability will prove to be the most consequential discipline of the twenty-first century.

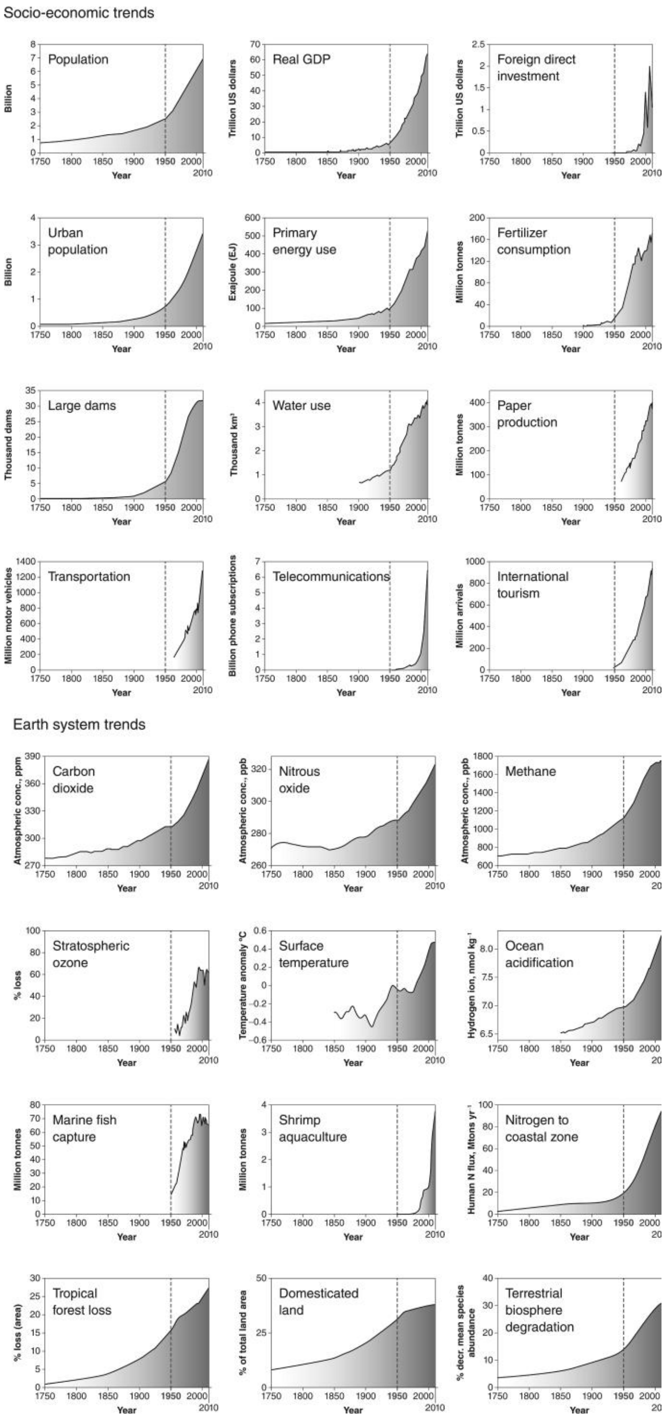

Figure 2.1 Socio-economic and Earth system trends of the Great Acceleration from 1750 to 2010.

Source: Will Steffen et al., "The Trajectory of the Anthropocene: The Great Acceleration." *Anthropocene Review.* January 16, 2015.

Notes

1. This was not the first fire on the Cuyahoga River, which caught fire at least 13 times beginning in 1868. The 1952 fire was the most damaging. Other rivers and canals in Britain and the US served as industrial sewers in the nineteenth and twentieth centuries, and occasionally caught fire (Zalasiewicz et al. 2019, 253).
2. Japan, France, and Canada had already created such bodies in 1971.
3. The OECD sets standards and informs policy; it is not a governmental body.
4. The UBA operates under the jurisdiction of the Federal Ministry of the Environment, Nature Conservation, and Nuclear Safety.
5. Although placed at a high level of authority within the government, early on the ministry, whose official title was the *Ministère de la Protection de la Nature et de l'Environmenement*, was hampered by a small budget and lack of recognition (Bess 2003, 83).
6. Utilitarianism is the view that we ought to maximize the good and is summarized by the phrase, "the greatest good for the greatest number."
7. Jane Goodall is a founding board member.
8. A Renaissance analog to this change in perspective occurred in 1336 when Petrarch did something unheard of at the time: he climbed a mountain, Mont Ventoux, and wrote about seeing the world from a high elevation in a famous letter, *Familiaris IV, I* (Lokaj 2006, 13). Scholars debate when and how he actually climbed it; nevertheless, his description profoundly changed humanity's view of nature for those who were able to read it (Rogers 2001, 127).
9. The name "Agenda 21" originated in an Earth Summit planning meeting that proposed laying out how to make planet sustainable by the beginning of the 21st century (Adams 2008, 90).
10. The epoch that preceded the Holocene is called the Pleistocene. It was a time of recurring ice ages.
11. The ICS contains a number of subcommissions, including the Subcommission on Quaternary Stratigraphy (SQS). The Quaternary is the geological period that covers the Pleistocene, the Holocene, and soon, the Anthropocene Epochs. The Anthropocene Working Group was established in 2009 by the SQS (Zalasiewicz 2019, 269).

Further reading

Burke, Edmund E., III and Kenneth Pomeranz, eds. *The Environment and World History*. Berkeley, CA: University of California Press, 2009.

Caradonna, Jeremy L. *Sustainability: A History*. New York: Oxford University Press, 2014.

Nash, Roderick Frazier. *The Rights of Nature*. Madison: University of Wisconsin Press, 1988.

Zalasiewicz, Jan., Colin. N., Waters, Mark. Williams, and Colin. P. Summerhayes, eds. *The Anthropocene as a Geological Time Unit: A Guide to the Scientific Evidence and Current Debate*. Cambridge, UK: Cambridge University Press, 2019.

Chapter review

1 In what ways are the environmental movement and the sustainability movement different?
2 What are some of the benefits of environmental regulations?
3 Why was DDT seen as beneficial?
4 What approaches did Rachel Carson use in *Silent Spring* to argue against indiscriminate pesticide use?
5 During the 1950s and 1960s it was reported that rivers caught fire. How is this possible?
6 If your 10-year-old neighbor asked you "What was Love Canal?" what would you say?