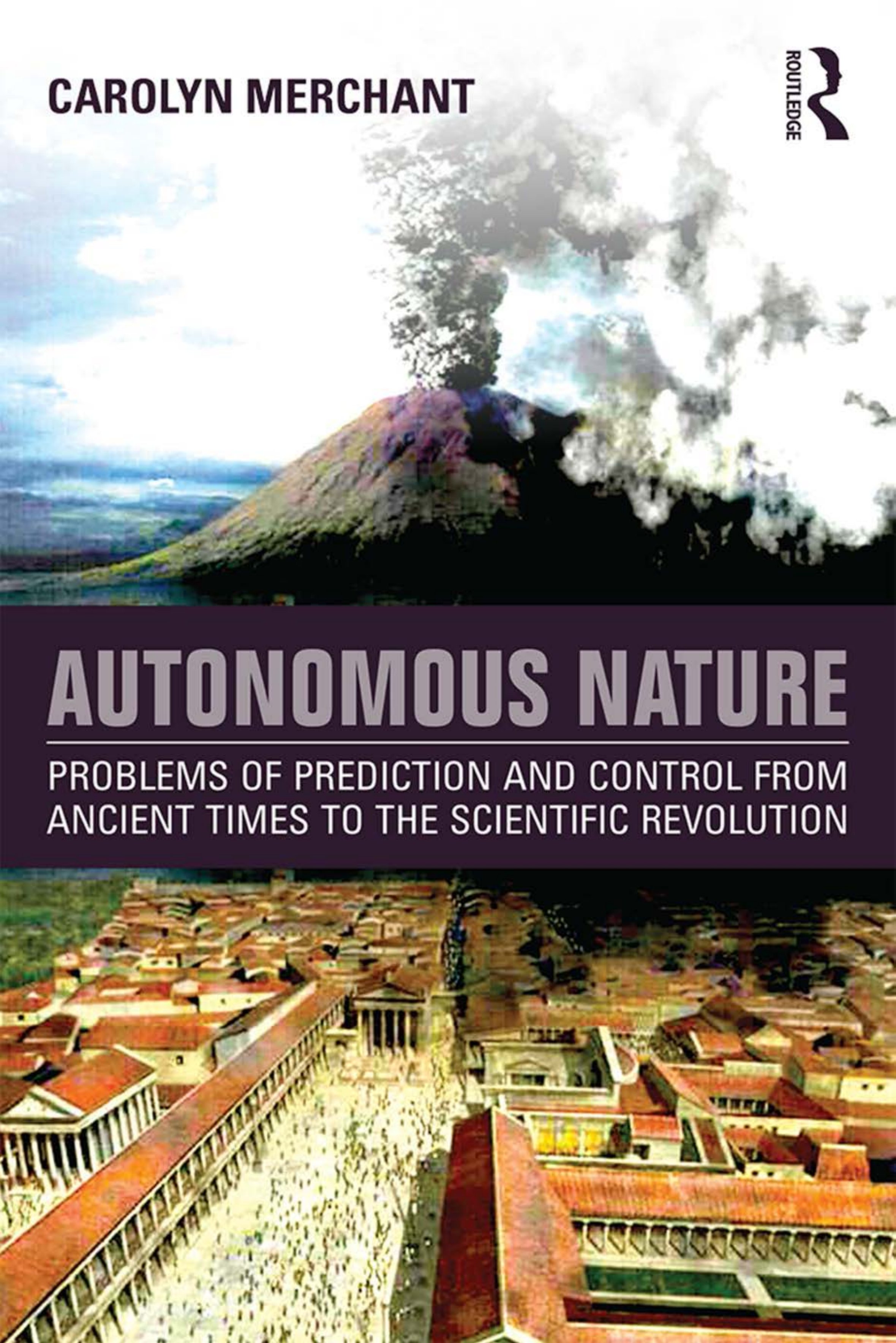
CAROLYN MERCHANT

ROUTLEDGE



AUTONOMOUS NATURE

PROBLEMS OF PREDICTION AND CONTROL FROM ANCIENT TIMES TO THE SCIENTIFIC REVOLUTION

Autonomous Nature

In this ambitious history of ideas, Carolyn Merchant calls attention to the ancient idea of nature as unpredictable, rebellious, and impossible to understand and control completely. She urges us to recover that older idea for the foundation of a new ecological ethic. Wide-ranging, original, and provocative.

Donald Worster, author of "Nature's Economy:
A History of Ecological Ideas"

Merchant has written a key history of ideas for evaluating two of the big questions today: how did we get into this mess, and how can we get out of it. Western thinkers, who gave us the scientific method, also fell short of the truer, fuller view of reality, dynamical and chaotic. It is against this richer backdrop that we can grasp today's emerging complexity paradigm, and find hope and insight for restoring our planet's beautifully 'rambunctious gardens.'

Jennifer Wells, California Institute of Integral Studies,
author of Complexity and Sustainability

Autonomous Nature investigates the history of nature as an active, often unruly force in tension with nature as a rational, logical order from ancient times to the Scientific Revolution of the seventeenth century. Along with subsequent advances in mechanics, hydrodynamics, thermodynamics, and electromagnetism, nature came to be perceived as an orderly, rational, physical world that could be engineered, controlled, and managed. *Autonomous Nature* focuses on the history of unpredictability, why it was a problem for the ancient world through the Scientific Revolution, and why it is a problem for today. The work is set in the context of vignettes about unpredictable events such as the eruption of Mt. Vesuvius, the Bubonic Plague, the Lisbon Earthquake, and efforts to understand and predict the weather and natural disasters. This book is an ideal text for courses on the environment, environmental history, history of science, or the philosophy of science.

Carolyn Merchant is Professor of Environmental History, Philosophy, and Ethics at the University of California, Berkeley. She is the author of The Death of Nature; Ecological Revolutions; and Reinventing Eden among other books. She is a past president of the American Society for Environmental History and a recipient of the Society's Distinguished Scholar Award.

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Autonomous Nature

Problems of Prediction and Control from Ancient Times to the Scientific Revolution

Carolyn Merchant

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For David and John

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Preface

Autonomous Nature stems from a desire to understand the roots of the idea of nature as an active, sometimes disruptive and unruly entity in the past and present. Manifested most dramatically in the effects of climate change, natural disasters, habitat transformations, species dislocations, and the loss of human homes and lives, such disruptions result from ecological tipping points and cascading effects that are often unpredictable and uncontrollable.

This book is intended for those with a background in the humanities, social sciences, and the sciences and for an educated audience interested in the past, present, and future of humanity and life on earth. It proposes that the new sciences of chaos and complexity theory not only constitute a new paradigm for twenty-first century science, but are the basis for a new ethic of partnership with a nature that must be considered as autonomous and often unpredictable. To understand how humanity has arrived at this new paradigm and environmental ethic, this book investigates the early history of nature in Western culture.

Autonomous Nature explores the idea of nature in the Western world from ancient times to the (so-named) Scientific Revolution of the seventeenth century as an active, chaotic, unruly, and unpredictable actor/actress and the ways in which natural scientists and philosophers sought to control and manage it for human benefit. It looks at the tensions between order and chaos, stability and change, predictability and unpredictability. It delves into well-known texts of the past, looking, in particular, for what they said about disruption, disorder, and disaster and how to deal with the uncertainties of nature, both philosophically and in the everyday world. In so doing, it reframes and reinterprets many well-known works, focusing especially on ancient and early modern European culture.

The book draws on familiar authors and events, but its goal is to reread them in ways that shed new light on twenty-first century problems, in particular the often unanticipated effects of natural disasters and climate change. Using the new sciences of the late twentieth century, as guidelines and lenses, it looks at the history of the unruliness and unpredictability of nature in the early texts of Western culture. It does not intend to cover all individuals or events equally or to deal with non-Western cultures, but rather to select those texts that shed light on the prehistory of chaos and complexity theory. And while many histories of science presuppose progress, order, and the emergence of new ideas, this book looks at ideas of disorder and the ways that natural philosophers sought to subdue it.

Since the early 1990s I have been writing about nature as an autonomous actor and humanity in partnership with nonhuman nature. At the Earth Summit in Rio de Janeiro in 1992, I formulated what I call a "partnership ethic" which holds that "the greatest good for the human and the nonhuman community is to be found in their mutual living interdependence." (See "Conclusion: Partnership Ethics," in my 1996 book, *Earthcare*.)

My book also goes back to a question that arose during the 1970s as I was writing *The Death of Nature* (1980). What were the origins and influences of the terms *natura naturans*, or nature creating, and *natura naturata*, the created world? Those concepts were discussed by R.G. Collingwood in his 1939 book, *The Idea of Nature*, and by Eustace Tillyard in *The Elizabethan World Picture* (1959). In *The Death of Nature*, I wrote about the idea that nature, depicted as a female during the Renaissance, seemed not only to be the instrument of God, but also to exhibit a will of "her" own. Since then, as I have investigated the origins of chaos and complexity theories that emerged in the 1970s and 1980s, I have returned to the history of nature depicted as willful, unlawful, and hence unpredictable. In addition to *The Death of Nature*, I referred to *natura naturans* and *naturata* in several places including *Ecological Revolutions* (1989) and *Reinventing Eden* (2002). I also raised the question of the origin of these two terms in conversations with historian of medieval science Amos Funkenstein in the 1990s, who promptly answered, "it was *natura creans* and *natura creata*" and philosopher J. Baird Callicott who said, "Spinoza used them, but in a different way."

In 2012–13, I received a fellowship from the American Council of Learned Societies to study the topic, "Ideas of Nature: Emerging Concepts of Law and Nature in the Scientific Revolution," that focused on the history and meaning of those two concepts. I am deeply grateful for their support. I was also invited to work on the project at Princeton's Institute for Advanced Study (IAS) during the fall term of 2012 with support from the Mellon Foundation. At IAS I am indebted to Jonathan Israel, Irving and Marilyn Lavin, Hyun Ok Park, Anne-Lise Rey, Frans van Liere, and especially to Heinrich von Staden for conversations, references, and insights and to the staff of the Institute for library and housing support. At Princeton University I wish to thank Daniel Garber and the university's librarians. In addition, I very much appreciate the response of Brother Alexis Bugnolo in Rome to my inquiries regarding Saint Bonaventure's *Commentaries on the Sentences of Peter Lombard* and for his translations of the Latin passages discussed in the notes to Chapter 2 on "Christianity and Nature."

I am especially indebted to Francesca Rochberg with whom I collaborated on a UC Berkeley Townsend Center for the Humanities Collaborative Research Seminar entitled "Nature/No Nature: Rethinking the Past, Present, and Future of Nature in the Contemporary Humanities." During the spring semester of 2012, together with faculty colleagues and graduate students in the humanities and sciences, we explored the origins and meanings of nature, focusing primarily on the history of Western culture. I am indebted to Francesca's inspiration and support as well as to the seminar members for their insightful and scholarly contributions and for the support of the Townsend Center. The University of California at Berkeley awarded me sabbatical leave during 2012 and the Committee on Research provided me with a Faculty Research Grant (FRG) and a Humanities Graduate Student Research (GSR) Grant for 2012.

I also wish to thank Sheila ffolliott for her references and insights into Renaissance art and David Kubrin for numerous conversations over the past years and references on seventeenth-century science and society. Robert Westman offered many insights into reappraising the issue of the "scientific revolution." Jennifer Wells shared her ideas about complexity theory and her book on *Complexity and Sustainability* (2013) as it has evolved over the past few years. Ken Worthy engaged in conversations with me about *natura naturans* and shared ideas for his book on *Invisible Nature* (2013). I am particularly indebted to all those who read chapters of the manuscript for their astute comments and helpful suggestions for improving the argument. I especially thank Celeste Newbrough for the index to this and previous books and to Ted Grudin for his suggestions and careful reading of the manuscript.

Thank you also to the Routledge reviewers: Glenn Fieldman, San Francisco State University Yan Gao, University of Memphis Jennifer Wells, California Institute of Integral Studies Marco Armiero, Royal Institute of Technology, Sweden.

My son David Iltis urged me to include the ways in which societies achieved buffers against nature, and my son John Iltis discussed the ramifications of the history of astronomy for the project. On trips across the country, my husband, Charles Sellers, offered numerous real-time examples of *natura naturans* and suggested the title *Autonomous Nature* as the best way of capturing the idea of the book. I am of course responsible for the results as well as any errors herein.

Carolyn Merchant
Berkeley, California

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Introduction

Can Nature Be Controlled?

In the late fifteenth century B.C.E., a series of tsunamis radiated outward from a collapsed volcanic caldera in the Aegean Sea, just north of the island of Crete. Enormous waves rolled across the waters inundating land and peoples in their wake. In the path of the disaster was the Minoan civilization of Crete. It is hypothesized that this calamity, caused by a volcanic eruption, may have destroyed the ancient center of Minoan power, its natural resources, naval dominance, and culture.[1]

What are the implications of such chaotic events for science, politics, and the human future? Is the natural world fundamentally unpredictable, and, if so, can humans learn to live within it? Can science predict and therefore control the outcomes of catastrophic events? The historical relationship between the unpredictability of nature and human efforts to control it is the subject of this book. In it, I look at meanings of "nature" and the "natural" and at the roots of ways to manage the natural world. I argue that twenty-first century humanity is in the throes of a paradigm shift, one that is triggered by two factors: the rise of the new sciences of chaos and complexity and by climate change as the most widespread catastrophe for the human future. Chaos and complexity, unlike the more mechanistic sciences of the past, challenge our ability to predict with perfect certainty. Because chaotic systems are sensitive to initial conditions, uncertainty increases exponentially with elapsed time. Complexity, which deals with an extremely large number of dynamic sets of relationships, limits the degree of predictability. Climate change is both global in scope and cumulative in effect, reflecting these uncertainties and limits to predictability. New ways of living within the everyday world are therefore needed.

In what follows, I explore the prehistory of chaos and complexity theory from ancient times in the Western world to the (so-named) Scientific Revolution of the seventeenth century. I look at ideas of an unpredictable, unruly, and recalcitrant nature that captured the imaginations of ancient, medieval, and early modern European peoples and triggered efforts by seventeenth- and eighteenth-century scientists to find ways of predicting and controlling the world around them. In so doing, I hope to cast a new light on ways of thinking about nature and science in the past.

A New Paradigm for the Twenty-First Century

In 1962, Thomas Kuhn published his foundational work, *The Structure of Scientific Revolutions*.[2] In it, he argued that major transformations in the history of science have been triggered by anomalies that do not fit into accepted theories. These transformative moments resulted in new scientific paradigms that over time became accepted as mainstream science. Such changes, however, can reach far beyond the confines of the scientific laboratory or institution to encompass society, politics, philosophy, and ethics. The Scientific Revolution of the seventeenth century is a prime example of a transformation in science that wrought changes in the wider society. Its greatest achievement was its understanding of the earth as a mechanism that could be understood, predicted, and controlled. A second example is the Scientific Revolution in Relativity Theory and Quantum Mechanics in the early twentieth century that followed the great triumphs of classical Newtonian mechanics in hydrodynamics, thermodynamics, and electromagnetism and in mathematics by differential equations, probability theory, and statistics. These advances, however, began to introduce uncertainties into the mechanistic worldview of Newtonian science.

Today, in twenty-first century America, we are in the midst of a third major paradigm shift. That paradigm is the wide-reaching societal transformation triggered by the rise of chaos and complexity science in the 1970s and 1980s.[3] The main achievement of seventeenth-century science was predictability; the main feature of the chaos paradigm is unpredictability. Although some scholars prefer to emphasize historical continuities and the history of science as prediction, in this book, I focus instead on transformative periods and the history of unpredictability.

Before proceeding further, however, a word of caution is needed. Although predictability and unpredictability are often cast as polar opposites, it should be noted that a range of possibilities exists between them, as well as levels and degrees of chaos, and a mixing of chaotic and deterministic systems. Charlotte Werndl points out that "it is widely believed and claimed by philosophers, mathematicians, and physicists alike that chaos has a new implication for unpredictability, meaning that chaotic systems are unpredictable in a way that other deterministic systems are not. . . . " But, she notes, there can be combinations of order and disorder at both large and small scales from the everyday world of macro-predictability to the subatomic world of micro-unpredictability, as well as predictable patterns in chaotic systems. Thus while one of great achievements of the Scientific Revolution of the seventeenth century was predictability in terrestrial and celestial mechanics, with wide-ranging consequences for the world in which we live today, subsequent advances in probability theory, statistics, quantum mechanics, relativity, chaos theory, and quantum computing have introduced uncertainties, variabilities, and probabilities into all fields of science.[4]

A major reason that I believe a history of unpredictability is important is the role that natural disasters and climate change play in the twenty-first century. Unpredictability is especially apparent in events such as hurricanes, tornadoes, earthquakes, droughts, and floods. And although climate change is largely anthropogenically caused and scientists can model and predict much of its extent, many outcomes are the result of unanticipated tipping points and complex cascading effects that, even if predicted, cannot be controlled. Because of the complexities of oceanic and atmospheric interactions, the moments, locations, results, and long-term effects of weather and climate make decision making highly problematic. The skepticism of climate-change doubters and the seeming inability of some lawmakers to promote the technologies and develop the regulations to manage and control changes and to prevent them from affecting individuals, communities, markets, and governments is of paramount concern. The long-term future of the earth itself is at stake.

In her book, *Complexity and Sustainability* (2013), Jennifer Wells argues that complexity represents a comprehensive new framework that encompasses the physical, biological, and social sciences. The transition to chaos and complexity that began in the 1970s and 1980s in the natural sciences now includes social theory, philosophy, and ethics and applies to the future of life on the planet. Wells writes that

> visions of complexity and sustainability have been emerging and developing in consort. Complexity theories have helped to rid us of falsely assuring assumptions of control and stability, and rather, show just how our planet is uncertain, vulnerable and resilient. . . . As such, complexity also touches the core of some of our oldest philosophical questions . . . all of which are necessary to understanding our current moment of momentous global change.[5]

Sustainability represents a new goal toward which human efforts must now be directed. New policies and ethics that deal with the environmental crisis and especially with global climate change are vital to new ways of living within a nature now characterized by uncertainties, nonlinearities, and unforeseen events. "In just a few decades," Wells argues,

> complexity science has flourished into not just a major new field, but also *the basis of a new paradigm*. Discoveries of complex dynamic systems, relevant across the widest range of area of reality—physical, living, and social systems—may play a central role in rearticulating our goals of sustainability.[6]

The big advantage of the clocklike, mechanistic universe was that it dealt with closed systems isolated from the environment. From the knowledge of initial conditions, the state of a particular system for any time in the future could be predicted with great accuracy. Living within a mechanistic world in which predictions hold gives confidence in everyday life that crossing bridges, flying across oceans, and lighting and heating our homes will be safe and secure. Only in very rare instances does chance disrupt such expectations—an earthquake of extremely high magnitude causing a bridge to collapse, a sudden lightning strike of such force that a plane is broken into pieces, a tornado that sweeps up a home and destroys it. But such external environmental disruptions are the result of unpredictable random events in situations that are highly localized in time and place. Within the mechanistic paradigm they are extremely unusual, not the usual events of everyday life. In the chaotic paradigm, on the other hand, external, environmental factors can play a major role, becoming the usual, rather than the unusual. Unpredictability and limited predictability become the new norms.

Meanings and Levels of Chaos

Biologist Daniel Botkin, in *The Moon in the Nautilus Shell* (2012) argues that there are several levels of chaos and hence of unpredictability, from well-behaved chance all the way to complete chaos without form or structure (in the sense of the ancient Greeks and Romans). The most predictable form follows probability theory, an example being the throwing of dice. The outcome over many, many throws follows a pattern of inherent randomness with the most likely outcome being seven. “While each throw has an unknown outcome, overall the game has a very regular, reliable, predictable behavior.” Over time, the probabilities are well ordered and dependent only on the dice without the external environment playing a role. “This,” says Botkin, “is the most predictable kind of chance: a process that has some inherent randomness but whose probabilities—chances of what will happen—are fixed forever and independent of everything else.” Probability theories have their roots in eighteenth- and nineteenth-century advances by mathematicians such as Jacob Bernoulli (1654–1705), Carl Friedrich Gauss (1777–1855), and Pierre Simon LaPlace (1749–1827).[7]

The next level of chaos includes the environment. Here predictability depends on knowledge of the interactions among the parts of the system being studied and external environmental factors, such as the behavior of a pack of wolves in relation to conditions such as snow and the availability of food. The better the connections are understood, the better the ability to predict on average what the pack might do. “But once again,” Botkin points out, “we cannot know perfectly, exactly, the future of any specific series of events.” Probability and statistics are of special interest in applications in forestry and environmental science. These mathematical tools are especially useful in dealing with localized environmental problems such as the impact of fire or disease on forests or the role played by the introduction or loss of a species in a grassland, lake, or river system.[8]

The next levels of uncertainty introduce ever increasing degrees of randomness. Here probabilities and hence predictions can be calculated with rapidly diminishing reliability. “And so on downward,” Botkin continues, “until one reaches what I will call complete chaos, an imaginary world where there is no cause and effect and that world is therefore without form, structure, and anything that we would call ‘understandable’ in normal terms.”[9] At these higher levels of uncertainty, new ways of understanding and living within nature become important. Climate change is the most challenging aspect of uncertainty in the twenty-first century because of its global dimensions.

Botkin argues, however, that computers give us an advantage in living in this new world of uncertainty. We do not dwell in a world of complete chaos of the type envisaged by the Greeks, but one of multi-leveled complexity. Because computers can handle vast amounts of data with very high speeds, they go beyond the limitations of older models and methods based solely on probability theories and stochastic processes. Computers allow us to make predictions that involve chance and to adapt to a world in which internal and external factors, living and nonliving things, and mechanistic and organic worldviews are blurred and blended.[10]

While Botkin maintains an agnostic position on the human role in climate change, he nevertheless advocates real-world solutions to confront numerous, very real environmental problems. "Whether or not we cause climate change, these changes greatly affect us and all life, and we need to take these changes seriously while remaining scientifically objective." Actions include reversing the effects of deforestation, overfishing, species depletion, invasive species, environmental pollution, and threats to biodiversity. He further notes that in contrast to received views, the greatest government subsidies are actually for fossil fuels and nuclear power, while those for solar and wind energy, by contrast, receive a mere pittance.[11]

What we need, argues Botkin, is "a fundamental change in our paradigm," one in which we understand that "complicated, intricate, always changing system[s] . . . respond to novel input[s]." We must therefore give up the comfort and security of the clocklike world and embrace the complexities of nature. "We who work on environmental sciences and on global warming need to open ourselves to a much greater variety of ways of thinking about nature. We need to develop forecasting methods appropriate for always-changing, non-steady-state systems where chance—randomness—is inherent." Acknowledging that we live in a world in which chance and randomness are the norm could lead to new ways of engaging with nature.

> [W]e must accept nature for what we are able to observe it to be, not for what we might wish it to be. Accepting this perception of nature, we discover that we have the tools to deal with it. And once we realize we have the tools, this new idea of nature takes on its own appeal.[12]

What Botkin suggests is that we need to accept the fact that we are now living in a world defined in terms of several levels of chaos, in which there are levels of predictability, and in which the random actions of nature are the new norm. We therefore need new policies, new ethics, new scientific tools, and new ways of living within this new nature.

Wells's and Botkin's points about the importance of chaos and complexity are echoed by Sandra Mitchell in her book *Unsimple Truths: Science, Complexity, and Policy*. Mitchell, in a section on "Shifting Paradigms in Epistemology," notes that

> The successes of the Scientific Revolution of the seventeenth century in providing simplifying, unifying representations, in particular Newton's laws of

> motion and his law of universal gravitation, led philosophers to define what they would admit as reliable knowledge in like terms. . . . But the world of Newtonian science did not persist. Twentieth century physics challenged some of its most fundamental assumptions.

In making her "Case for Complexity," Mitchell argues that complexity requires new modes of understanding. In particular, "we need to expand our conceptual frameworks to accommodate contingency, dynamic robustness, and deep uncertainty."[13]

While Wells, Botkin, and Mitchell make the case that a new paradigm and new ways of understanding and describing the world of the twenty-first century are needed, my book looks at the prehistory of chaos and complexity from ancient times to the Scientific Revolution of the seventeenth century. I do not claim to make a comprehensive history of that era, but rather to look specifically at authors who dealt with unpredictability and chaos. Nor do I attempt to write a history of challenges to Newtonianism and mechanistic thought in the eighteenth through twentieth centuries. Instead, although I recognize the advances that took place in the sciences of hydrodynamics, thermodynamics, and electromagnetism, in the mathematics of probability and statistics, and in the revolutions in relativity theory and quantum mechanics (see below and Chapters 6 and 7), my goal here is to look at early thinkers in the Western world to see how they met the challenge of dealing with uncertainty, chaos, and unpredictability.

Climate Change

The world of the twenty-first century is one in which chance and randomness constitute our new reality. The new paradigm is exemplified most dramatically by global climate change. In 2013, observations on the level of atmospheric CO_2 conducted over several decades at Mauna Loa Observatory in Hawaii hit a landmark 400 parts per million (ppm), reaching 403 ppm in June 2015. Since the Industrial Revolution of the eighteenth century and the burning of fossil fuels—an era named the anthropocene—levels of CO_2 have risen dramatically. Many believe that although a safe level of CO_2 is 350 ppm, that level could rise to a dangerous 450 ppm within a few decades. Such rises in CO_2 could trigger an ecological tipping point in which a tiny fluctuation could initiate a series of cascading effects on organisms and their interactions and dependencies. Such a point of no return would herald a series of drastic impacts on human life support systems. At such threshold points, the changes and effects become fundamentally unpredictable.[14]

According to Edward Lorenz, chaotic behavior can be observed in many natural systems, especially weather and climate. In such dynamical systems, small differences in initial conditions can result in widely differing outcomes, making long-term predictions impractical if not impossible. While such systems might, in principle, be deterministic, over time random unpredicted changes can occur. In climate change, for example, small changes in global temperature can lead to unexpected and abrupt changes in ecosystems from oceans to rainforests. Here the rapid doubling of errors precludes great accuracy in real world forecasting. Lorenz argued that we cannot predict the results of small effects such as a butterfly on the weather, because the atmosphere is unstable with respect to perturbations of small amplitude. We don't know how many small effects there are (such as butterflies) or even where they are located. We can't even set up a controlled experiment to find out if the atmosphere is unstable because we can never know what might have happened if we hadn't disturbed it. Unstable dynamic systems, such as weather and climate, behave differently than stable systems, such as the planetary systems described by Isaac Newton. In such cases predictability is limited or unfeasible.[15]

The problem of predictability and control was pushed further by Ilya Prigogine in his work with Isabelle Stengers on *Order out of Chaos*. While classical thermodynamics, discovered in the nineteenth century, described equilibrium and near-equilibrium situations, as in the steam engine and refrigerator, in Prigogine's far-from-equilibrium thermodynamics, as found in hydrodynamics, many chemical processes, and evolution, a new reorganization can occur in which order can emerge out of chaos. In such situations irreversibility and nonlinearity can lead to self-organization. Irreversibility and nonlinearity increase the role of fluctuations and lead to bifurcations (divisions) in which the system can go in several directions because nonlinear equations can have several different solutions. The outcome, therefore, cannot be predicted with certainty and the control of nature is problematic.[16]

As Prigogine puts it:

> The important element is that unstable systems are not controllable. . . . The classical view on the laws of nature, on our relation with nature, was domination. That we can control everything. If we change our initial conditions, the trajectories slightly change. . . . But that is not the general situation. . . . We see in nature the appearance of spontaneous processes which we cannot control in the strict sense in which it was imagined to be possible in classical mechanics. . . . The world in which we are living is highly unstable. . . . [17]

Today we are living within a new paradigm in which nature is autonomous. Our world is characterized, not by determinism and predictability, but by several levels of unpredictability and degrees of forecasting. During the twenty-first century we have the opportunity to halt and even reverse the mounting effects of global warming on human and nonhuman life. As I wrote in *Earthcare* and other works in the 1990s, chaos theory

> reinforces the idea that predictability while still useful, is more limited than previously assumed and that nature, while a human construct and a representation, is also a real, material, autonomous agent. . . . Because nature is fundamentally chaotic, it must be respected and related to as an active partner through a partnership ethic.[18]

We must find new ways to live within nature, to stem the effects of climate change, and to halt the loss of species and collapse of populations. Ways of living