What Should a Clever Moose Eat?

NATURAL HISTORY, ECOLOGY, AND THE NORTH WOODS

JOHN PASTOR

FOREWORD BY BERND HEINRICH

What Should a Clever Moose Eat?

What Should a Clever Moose Eat?

NATURAL HISTORY, ECOLOGY, AND THE NORTH WOODS

John Pastor

Illustrated by the author

ISLANDPRESS

Washington | Covelo | London

Copyright © 2016 John Pastor

All rights reserved under International and Pan-American Copyright Conventions. No part of this book may be reproduced in any form or by any means without permission in writing from the publisher: Island Press, 2000 M Street NW, Suite 650, Washington, DC 20036

Island Press is a trademark of The Center for Resource Economics.

Library of Congress Control Number: 2015937835

♻️ Printed on recycled, acid-free paper

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

Keywords: Adirondacks, balsam fir, beaver, blueberries, boreal forest, fire, food web, glaciation, ice sheet, Lake Superior, life cycles, life histories, Maine, maple, Minnesota, moose, moraines, natural history, North Woods, pine, pollen analysis, spruce budworms, spruce, tent caterpillar, voyageurs

*For my grandson,
Laszlo Pastor*

Everything changes; everything is connected; pay attention.

—Jane Hirshfield

Contents

List of Drawings xiii

Foreword xv

Preface xix

Prologue: The Beauty of Natural History xxvii

Introduction: The Nature of the North Woods 1

Part I: The Assembly of a Northern Ecosystem and the European Discovery of Its Natural History 19

1. Setting the Stage 21
2. The Emergence of the North Woods 35
3. Beaver Ponds and the Flow of Water in Northern Landscapes 49
4. David Thompson, the Fur Trade, and the Discovery of the Natural
History of the North Woods 57

Part II: Capturing the Light 65

5. How Long Should a Leaf Live? 67
6. The Shapes of Leaves 79
7. The Shapes of Crowns 91
8. How Should Leaves Die? 101

Part III: Foraging, Food Webs, and Population Cycles of Predators and Their Prey 111

9. Foraging in a Beaver's Pantry 115

10. Voles, Fungi, Spruce, and Abandoned Beaver Meadows	123
11. What Should a Clever Moose Eat?	131
12. Tent Caterpillars, Aspens, and the Regulation of Food Webs	143
13. Predatory Warblers and the Control of Spruce Budworm in Conifer Canopies	151
14. The Dance of Hare and Lynx at the Top of the Food Web	159
Part IV: Pollinators, Flowers, Fruits, and Seeds	171
15. Skunk Cabbages, Blowflies, and the Smells of Spring	175
16. When Should Flowers Bloom and Fruits Ripen?	181
17. Everybody's Favorite Berries	189
18. Crossbills and Conifer Cones	197
Part V: Fire and the Dynamics of the Landscape	205
19. Does Fire Destroy or Maintain the North Woods?	207
20. The Legacies of a Fire	219
21. Fire Regimes and the Correlated Evolution of Serotiny and Flammability	227
Epilogue: Climate Change and the Disassembly of the North Woods	237
Postscript: The Natural History of Beauty	245
<i>Notes</i>	255
<i>Glossary</i>	263
<i>Bibliography</i>	269
<i>Index</i>	289

List of Drawings

- The snout of an ice sheet 24
- A grooved cobble with chatter marks from the Superior Lobe of the
Laurentide Ice Sheet 29
- Pollen grains of pine, birch, and maple 36
- Beaver dam and pond 53
- Aspen leaf and red pine needles 68
- Measuring how lobed maple leaves are (after Horn, 1971) 81
- Aspen stump left after a beaver felled the tree 119
- Tent caterpillars on aspen leaves 144
- Lynx–hare cycles 162
- Skunk cabbage flower 176
- Juneberry flowers 184
- Blueberries 190
- The beak of a crossbill 199
- A closed jack pine cone before a fire and a cone opened by a fire 228
- Wild plum flowers and honeybee 251

Foreword

Bernd Heinrich

Eighteen thousand years ago most of northern North America was covered by the ice of mile-deep glaciers. By ten thousand years ago the ice had melted, creating a tundra habitat with ponds, lakes, eskers, moraines, and drumlins. A mere six thousand years ago this tundra became the North Woods, an ecosystem populated by beaver, hare, lynx, and moose, encompassing New England, Quebec, Ontario, Labrador, Wisconsin, and northern Minnesota.

For the past 30 years, John Pastor has studied the North Woods, and his book *What Should a Clever Moose Eat?* showcases his deep knowledge of this region. His insightful essays explore natural history questions and observations and delve deeply into how this ecosystem works. By extension, this book is not only about the North Woods; it is about the larger theme of how natural systems work and how we go about finding good questions and the answers to them.

The North Woods are “simple” in having fewer but often prominent species, allowing us to more easily observe how species affect the structure and complexity of the ecosystem. What a moose eats has easily measurable consequences, and as the chapter on moose illustrates, a single moose has a large effect on the cycling of nutrients through an ecosystem. Moose thus bequeath not only their genes to the next gen-

eration but also the landscape they created. The theme comes through in several other iconic and famous examples throughout this book, as we see this ecosystem in terms of its origin, its development, and its parts today.

Several stories in this book reveal effects that could not have been predicted. For example, conifers apparently do not invade meadows created by beavers. From one natural history observation and one experiment that led to the next, scientists determined that mycorrhizae and red-backed voles are critical variables, and together they answer the riddle of the excluded conifers. Similarly, studies revealed that tent caterpillars' periodic mass outbreaks are the result of arms races in which broad-leaved trees defend themselves against caterpillars, luring caterpillar-killing ants with sugary secretions. On a longer time scale, the population explosions and crashes of both hares and lynx are cyclical, and they have become a model system for studying populations thought to be related strictly through food. Exhaustive experiments indicated a correlation with sunspots.

This long time scale often hinders our understanding of an ecosystem. Predator-prey cycling between warblers and spruce budworm affect native northern spruce-fir forests over the course of a half century. But budworm defoliations could be made nearly chronic by new methods of timber harvesting and, counterintuitively, by the use of biocides to kill the budworms. As Pastor's examples show, tinkering with the ecosystem leads to surprises because of its unanticipated complexity. What applies to control of biological agents in a natural ecosystem applies to fire as well, and Pastor devotes a few chapters to showing how fire and browsing animals have left their imprint on the North Woods.

At least since the days of the fur trade, humans have left a vast imprint on the region. They began by nearly eliminating the beavers, but they also opened the region to explorers who returned not only with pelts but with new observations and discoveries that had consequences

for the North Woods and beyond. The Maine woods fascinated Henry David Thoreau, who in turn inspired George Perkins Marsh of Vermont, whose famous book *Man and Nature* provided a warning about the human imprint and scientific rationale for conservation, which led to the designation of the Adirondack Preserve in 1892 to preserve its lands as “forever wild.” The Adirondack model has been applied worldwide since then, as we realize that we simply do not and will not ever be able to understand it all. The North Woods provided a world model, and does so still.

“What should a clever moose eat?” is not just a rhetorical question. The answer has large consequences not only for individual moose but also for moosedom and entire ecosystems. Answering involves ecological, physiological, and evolutionary studies. But these studies would be futile, and even wrong, if not based on good natural history questions sparked by careful observations in the field. If nature teaches us anything, it is that it is complex, and seemingly little things can have huge consequences.

Preface

During the past several decades of my research on the forests, peatlands, beaver, moose, and other occupants of the North Woods, the idea slowly dawned on me that every good problem in ecology begins with a question or observation from natural history. To explore this idea, I began writing occasional essays about how organisms that live in the North Woods teach us something larger about the ecology of the world around us. These essays were short, about a thousand words, and were published many years ago in newsletters of the Voyageurs National Park Association and the Friends of the Boundary Waters Wilderness and in *Minnesota Forests*. In reading through these old essays a few years ago, I decided that I could rewrite and expand them to bring them up to date. As I did this, it occurred to me that if I wrote some more essays, I would have a book on the natural history of the North Woods and why and how natural history underlies all of ecology and most of biology and geology.

The result is this set of essays about the natural history of the North Woods and how natural history helps us understand the world better. An essay (from the French word *essayer*, “to try” or “to attempt”) is a foray into the unknown, an attempt to find some order in one’s world. This attempt to find order in the unknown is exactly the spirit with

which natural history is done. In this book I want to explore the varieties of approaches to nature that constitute good natural history thinking and where these approaches lead us, using the North Woods as my arena. In a way, the entire book is one extended attempt, or essay, to make sense of what we mean by “natural history” and why I and many others have come to appreciate anew its importance to the fields of ecology in particular and biology and geology in general.

This book takes a “layer cake” approach to the natural history of the North Woods. I begin at the lowest level of the cake with the formation of the landscape by the ice sheet that covered most of the current location of the North Woods 10,000 years ago. The ice sheet left a variety of landforms that determine the distribution of water, especially water held in the soil. The water in the soil in turn determined how the plants of North Woods, the next layer of the cake, assembled themselves into communities as the ice sheet retreated and they migrated into the land that emerged from beneath the ice sheet. Soon after, herbivores, pollinators, and seed dispersers arrived and formed the third layer of the cake. The fourth layer, the predators, arrived at about the same time as or immediately after the herbivores and pollinators. Native Americans and then European trappers and fur traders arrived, followed by loggers, and we became a fifth layer. Fires, especially in the drier part of the North Woods in the western Great Lakes region, periodically reset the landscape to bare soil, and the North Woods reassembles itself anew.

The main point of this book is that the North Woods or any other ecosystem is not simply a collection of species or a series of layers atop one another. The point I wish to make is that the connections between these species and layers—how water, energy, and nutrients flow between them, who eats whom and why, how different plant species promote or impede fires, how evolution continually shapes and reshapes these connections—are determined by the natural history of the organisms. Natural history is more than just identifying species and knowing what hab-

itats they are found in, although these are excellent starting points. The natural history of an organism includes its life cycle, how it responds to the seasons, what it eats and who eats it, how it reproduces, where it gets its energy and nutrients from, where the energy and nutrients go when they die, and how these traits have coevolved with other organisms in the food webs and ecosystems to which they belong.

The book takes you, the reader, up through the layers of this cake. Each set of essays builds on and elaborates topics described in previous essays. All the essays begin with some observation or question in natural history; those of us who live in the North Woods will be familiar with many of these just from our walks through the woods. After two introductory essays on the nature of natural history and the North Woods, Part I describes how the communities of plants and animals of the North Woods assembled themselves on the watery landscape the ice sheet left behind and how one important animal, the beaver, modified and still controls the flow of water. It closes with an essay on how one brilliant observer in the fur trade laid the foundation for the study of the natural history of the North Woods. Part II discusses how the life history and shapes of leaves and crowns of different plant species captures the sun's energy. Part III shows how the natural histories of herbivores and predators take the energy captured by plants and weave it into the food web. Part IV discusses how plants reproduce themselves through flowers and seeds, how animals pollinate, eat, and disperse these seeds, and how these reciprocal relations between plants and animals have evolved. Part V explores the idea that fire is a process that renews rather than destroys the North Woods and that some species have become adapted to and even need periodic fires to release and disperse seeds. A common thread throughout these essays is how natural selection has knitted these layers and connections between species into a functioning ecosystem. The book closes with an epilogue on the currently changing climate and the future (or demise?) of the North Woods and with a postscript of after-

thoughts on how we humans evolved an interest in the natural history of the world around us.

I hope this book finds a wide audience that includes intelligent non-scientists interested in the natural world, undergraduate and graduate students looking for potential research problems, and my colleagues. Although this is not a textbook about the North Woods, it could be used as supplementary text in ecology classes or as the main text in seminar classes. It could also be a sourcebook of ideas for research projects. I have tried to walk a fine line between scientific rigor and losing readers who may not be familiar with some scientific terms and concepts. Scientific terms are defined explicitly, by example, or by both when first mentioned, and there is a short glossary of **bold-faced** words at the end of the book. I have used metric units throughout rather than English because that is the accepted practice of science. For those who are not familiar with metric units, here's a brief introduction: A millimeter is the width of a spruce needle, the length of the fingernail on your pinkie is about a centimeter (if you keep it trimmed), a meter is about 3 inches longer than a yard, a kilometer is 6/10 of a mile, a hectare is about 2½ acres, a liter is slightly more than a quart, water boils at 100°C and freezes at 0°C, and -40°C is the same temperature as -40°F.

On the other hand, except in a few places, I have not used the scientific Latin names for plants and animals, such as *Betula papyrifera*, as is accepted taxonomic practice. The reason why I have generally avoided Latin names is that they would unnecessarily lengthen lists of species when I give them and also clutter the text. Beginning with Linnaeus in the 1700s, scientists began using Latin rather than common names because there were at that time so many common and colloquial names for many species, such as *white birch*, *paper birch*, *canoe birch*, or *silver birch* for *Betula papyrifera*, the familiar white-barked species depicted on the cover. The Latin names also have the advantage of indicating evolutionary relationships between species because the first name (*Bet-*

ula) indicates the genus within which closely related species depicted by the second name (*papyrifera* along with its relatives *alleghaniensis*, *cordifolia*, *nigra*, and *pumila*) are grouped. But with the development of field guides such as the Peterson series, common names have become less colloquial and more standardized, so *paper birch* is the accepted common name now for *Betula papyrifera*. If you want to learn the Latin names and more about the natural history of any species mentioned in this book, you can easily find them by entering the common name I use into a web browser. I recommend starting with *Wikipedia* and following up with the references at the end of the species page. The few exceptions where I use Latin names are where there are no standard common names for the species being discussed.

Scientists have learned to speak about the natural world using words such as *perhaps*, *maybe*, and *possibly* rather than in definite and absolute terms. This can frustrate nonscientists; there have been many times when people have asked me, “Why can’t you scientists just give us the answer?” The best scientists are by nature cautious. We are reluctant to make any firm pronouncement because we know it is always possible that a few more observations could force us to change our minds, or at least to rethink something. Instead we offer hypotheses, which are tentative explanations subject to change or abandonment when confronted with data, but starting sentences with “I hypothesize that . . .” sounds stilted. Using words such as *perhaps*, *maybe*, and *possibly* seems to me to be a gentler way to invite you to consider and explore a different way to view the world.

The scientific studies that supplied particular experiments or observations mentioned in the text are referenced in Notes at the end of the book. These Notes give the author’s last name and date of publication. You can find the full references in the Bibliography at the end of the book, which is organized according to the title of each essay. Many of these publications can be found online using search engines such as

Google Scholar, although you may need to be logged in through a university library to obtain the full text. These references should help any student or colleague who wants to follow up on some of these ideas. If I have mistakenly explained any research mentioned in these essays or provided the wrong citation, please let me know.

I could not have written this book without the advice and support of several organizations and people. Almost all of my research and that of many of my colleagues mentioned in this book has been funded by the National Science Foundation. This is one of the very best-run government agencies; more than 90 percent of the money it receives from Congress goes out to support students, technicians, faculty, and other scientists in their quest to understand the natural world. The National Science Foundation is an agency run by scientists for scientists. It is of great credit to this country that the National Science Foundation was established more than 50 years ago. Every new administration claims that they want to double funding for research supported by the National Science Foundation. I hope someday that actually happens.

My time writing this book was supported by a generous sabbatical leave from the Swenson College of Science and Engineering of the University of Minnesota Duluth. I thank Dean Emeritus James Riehl for awarding me this sabbatical and for his support of my work over the years.

Two people have read through every essay and have saved me from much grammatical embarrassment but more importantly called my attention to places that needed clarification so that you, the reader, would not be lost. They each deserve more thanks than I can express. The first is my wife, Mary Dragich, who corrected mismatches between verb tense and subject (there were many) and helped me clarify my thoughts. Mary also suggested several excellent examples that helped illustrate the points I was trying to make. I am ever grateful for her patience with me while I was working on this book and her patience and love at all other times as well.

Barbara Dean, my editor at Island Press, also read through every essay and made many helpful suggestions for clarification of difficult passages. Most importantly, Barbara helped me shape this book from a loose collection of essays with a staple through them (my first approach) to what I hope is a more coherent book that still maintains the informal and exploratory quality of a set of essays.

I also thank other members of Island Press for their unfailing assistance and support for this book. These include most notably Erin Johnson and Rebecca Bright for production support, David Miller, the publisher, and Maureen Gately, who designed the beautiful cover. It has been a pleasure working with all of you.

PROLOGUE:

The Beauty of Natural History

Why every good question in ecology and geology begins with an observation and question in natural history.

Naturalists and ecologists often ask questions that most people consider, well, peculiar. Such as “What should a clever moose eat?” When I once told my sister, who is not a scientist, that this was the question I was working on at the time, she looked at me and said, “Anything it wants to. Why should you care?” My sister asked a good question. The purpose of this book is to explain why she and other people who aren’t scientists, as well as other scientists, should care about the questions naturalists and ecologists ask.

Natural history is about particular organisms living in particular places, and the place of this book is the North Woods, the mixture of boreal conifers and northeastern deciduous species that stretches from Minnesota to Newfoundland. The North Woods is one of the most ecologically, geologically, and aesthetically interesting places on Earth. Here, glacial deposits from the Ice Ages lie atop some of the oldest rocks on Earth and support northern hardwoods and boreal conifers. Here, we find moose and beaver, the highest diversity of birds north of Mexico, and species with spectacular population dynamics such as

spruce budworm and balsam fir, lynx and hare, wolves and moose, and many others. These properties of the North Woods give us room to explore the breadth and depth of natural history and how it helps us frame ecological research.

The importance of natural history in initiating and guiding research questions is a recurrent theme throughout these essays. I think it was Dan Janzen who once said (I can't find where) that everything hinges on the details of natural history. The common threads through these essays include how the physical environment constrains ecological processes, how species interact with each other and the landscape, and how **evolution** by natural selection modifies these interactions.

Natural history asks questions such as "What does this organism do?" "What is its life cycle?" "How does that help it survive and reproduce?" "What does that mean for the other organisms it interacts with and the landscapes it inhabits?" "How does this landscape work, and how did it come to be?" Answering these questions requires sustained efforts to describe organisms and the places in which they live. The sustained collection of data to build a rich description of the patterns of a place was once derided by James Watson as "stamp collecting," but out of it can come rich and deep theories. Darwin did not set out to construct a theory of evolution in which sex and variation played prominent roles. Instead, the importance of sex in maintaining variation came to him during the course of describing all known living and fossil barnacles and their life histories.¹ The theory of natural selection and evolution then emerged and grew from Darwin's lifelong work on barnacles, pigeons, orchids, worms, and other species.

During the past 30 years in northern Minnesota, I have spent a lot of time thinking, "Why does a moose eat this plant and not that one, and what difference does it make?" The papers that my students, colleagues, and I have written are attempts (essays?) to answer them. For many years, we collected data to see what happens to the plant

community and the soils as moose populations wax and wane. We also used GPS collars, autoanalyzers, and gas chromatographs; developed mathematical models of moose energetics, plant growth, and nutrient cycling; analyzed data with a wide variety of powerful statistical techniques; and developed several competing hypotheses about what might happen. What often did happen was entirely different from any of these hypotheses. Nature is always more interesting than the hypotheses we first propose. Natural history teaches us to hold our theories and hypotheses lightly, to keep open to new observations, to not anticipate too rigidly what we are supposed to observe or measure. My questions—why does a moose eat this plant and not that one, and what difference it makes—emerged from watching and reading and thinking about what a moose does. In short, the natural history of moose suggested the questions and our experimental and mathematical approaches to answering them.

It is my firm belief that any good research problem in ecology and probably most of biology and geology begins with a natural history question or observation. There are many ways to do science, not just The Scientific Method of hypothesis testing, which we teach in freshman classes, with capital letters in the tone of our voices. Hypothesis testing is a powerful way to do science, to be sure. But before we can offer a hypothesis, design an experiment, or construct a model, we need to have a clear description of what it is about nature that we are trying to understand. Any hypothesis developed in a vacuum devoid of clear observations and descriptions will not be very interesting. When done at its best, natural history provides descriptions of nature that cry out for explanations and answers to some interesting observation, to some anomaly or asymmetry, or to some surprising questions about how an organism or landscape works. For instance, our understanding of how the North Woods arrived in its present location came from patiently constructed descriptions of pollen sequences in cores from hundreds of

lakes over many years, one lake and one core at a time. What surprised us was that the range of each species expanded northward independently and sometimes even at right angles to the expansions of others. In the beginning, no one would have come up with range expansions in perpendicular directions as a hypothesis of species migrations, but that's what happened. It still cries out for an explanation. As Walter Tschinkel and E. O. Wilson remarked, natural history produces "an abundance of serendipity" that keeps our minds fresh.²

Once a hypothesis is developed, we examine it further by experimental manipulation of one or more factors. Or we develop a mathematical model to work through whether the hypothesis logically follows from its premises. Or we use the model to make predictions that can be experimentally tested. But even in the experimental or modeling phase of the research, natural history is always guiding the decisions we must make. What portion of an organism's life cycle should be the focus of our experiments? What factors should we manipulate, and what levels of experimental treatments should we impose on the organism to test the hypothesis? What are the biological meanings of the equations in our mathematical models? There are an infinite (or at least very large) number of answers to these questions, but we make our choices guided by what we know about the natural history of the organism. For example, there is little point to testing the responses of an organism to nutrient concentrations well outside the range that the organism experiences in the wild. In order for a mathematical model to sharpen our biological insight, every variable and parameter must have a biological meaning that is almost always a property of the natural history of an organism, such as birth rate and lifespan, among many others. Natural history thinking is not done simply to describe nature or generate questions; it is (or should be) present throughout the course of research. I have confidence in scientific conclusions when natural history observations, experiments, and mathematical models all lead to the same conclusions,

but especially when natural history is the thread that binds them together. Always, we return to natural history.

Natural history is often defined as the study of organisms and their ecology,³ but organisms live in landscapes (or seascapes), and these have a geological history. Natural history bridges observations of an organism's life cycle, behavior, and interactions with other organisms with the geological history and structure of the landscapes in which it lives. Darwin was both a geologist and biologist, in modern terms, but in his letters, especially later in his life, he most frequently characterized himself as a natural historian.⁴ Darwin was the Grand Master at synthesizing keen observations on the natural history of organisms, mountain ranges, and coral reefs into powerful theories. *The Voyage of the Beagle* is best known for the chapter on the Galápagos. But the chapters on the rise of the entire Andean Cordillera are the ones that best demonstrate how Darwin developed general theories from natural history observations. In these chapters, Darwin showed how today's Andes could be explained by the many small repeated uplifts of the land in earthquakes similar to the one he experienced in Valparaíso, Chile. He later used the same type of reasoning to develop a theory of how the natural history of individual coral polyps controls the formation of massive coral reefs and atolls. The common thread through these studies was that large effects (mountain ranges, coral reefs) result from the accumulation of small repeated changes (earthquakes, growth and reproduction of individual coral polyps) over long periods of time. This thread later became a linchpin of Darwin's theory of evolution in the *Origin of Species*, which is one long catalog of natural history observations and questions that led not only to his theory of natural selection but also to several other general theories about how nature is organized. If you haven't browsed through the *Origin* recently, take a look at it. You will be pleasantly surprised. My favorite passage is when Darwin, after musing on red clover and violets, humblebees, mice, and

cats, invents the concept of a **trophic cascade**.⁵ Much of our research today is a series of footnotes to Darwin's natural history theories.

Natural history questions often arise from simple, serendipitous observations that anyone can make on a walk through the woods. Sometimes when a student comes to me asking for a research problem, I suggest that he or she take a walk in the woods and find a plant that intrigues him or her, even if only because it has pretty flowers. The aesthetic beauty of an organism will at least keep the student's attention focused until he or she develops a sense of the beauty of the question he or she will try to answer. I then give the student a List of Questions to Ask a Plant, which includes "Who pollinates you?" "How do you grow in full sun and in shade?" "How do you grow on different soils?" "How many seeds do you make?" "Do you make the same number of seeds each year?" "Who disperses your seeds, and when and where?" "Who eats you?" "Why do they eat you?" "What other plants do you associate with?" The answers to these questions, and more, describe the natural history of the plant. Unfortunately, we do not know these answers for most plants. Our predictions of how nature will respond to timber harvesting, climate change, hunting and gathering, invasion by exotic species, and other factors are severely limited by not having answers to these questions.

Although serendipity may put you in the right place at the right time to make a natural history observation, it does not guarantee you will ask a good question because of it. You have to be able to recognize that there is a good question lurking in the observation. What makes a good natural history question? This is harder to answer than it may at first appear. To a great degree, the value of a natural history question lies in the surprises generated by the research that attempts to answer it, so sometimes we only find out if it is good long after we ask it.

Many good natural history questions arise from observations made at human scales, such as the behavior of whole organisms or the landscapes

they reside in (well, maybe the human needs a microscope to observe zooplankton in a lake, but you get the idea). We widen the scope of these observations when we use them as springboards to make inferences or pose new questions about how the world works. This is the point where surprises often arise, and before we know it, we are going in a direction we didn't originally think we would travel. These new directions almost always connect our original observation with other levels in the biological hierarchy. Sometimes a natural history observation leads us to think about molecules, and sometimes it leads us to contemplate how the entire globe works. But the fascination of a natural history question is that *we do not know where and in what direction it will take us when we first ask it*. If we ask a molecular question, we are likely to get a molecular answer. This is not to disparage molecular biology, but it is to say that because natural history questions start in the middle of the range of the scales of nature, it allows us to go in more directions than if we started at one or the other extreme. Furthermore, we can keep coming back to our original natural history question, approaching it from several angles or from smaller or larger scales, and connecting it with other related questions. Anyone could spend a lifetime doing this with just one question, if it is a good one (see especially John Bonner's scientific memoir of his fascination with slime molds⁶). By focusing on questions at the organismal and human scale, natural history can help integrate the many different levels of biological organization, which are difficult to bridge because of different techniques, goals, and criteria for what constitutes excellence in research.⁷

Not every question about the natural world is a good natural history question. "How many leaves are on this tree?" is not an interesting natural history question because, although you can certainly answer it, it doesn't lead to other levels of biological organization. In short, it gets you nowhere. In contrast, "Why are leaves dispersed throughout an aspen's canopy but arranged in a shell at the perimeter of a maple's

canopy?” is a very good natural history question. Although anyone can make this observation, it was Henry Horn who developed it into a theory of the adaptive geometry of trees.⁸

A reason why this second question intrigues us (and perhaps intrigued Henry Horn) is because of the asymmetry in the different arrangements of leaves in aspen and maple: Why are the leaves arranged in opposite ways in these two species, which often grow together? Horace Freeland Judson called such asymmetric properties of nature that capture our attention “broken symmetries.”⁹ Broken symmetries catch our eyes, cause intellectual dissonance, and compel us to resolve them. Good natural history questions are often based on a broken symmetry that leads us in many directions. The broken symmetry between aspen and maple leaf arrangements also makes us think of other asymmetries between them, such as their very different shade tolerances and photosynthetic responses to light, the ovoid shape of an aspen leaf compared with the lobed shape of a maple, the differences in their relative growth rates, and many other properties. What are the connections between all these broken symmetries between aspen and maple? How did these evolve? How do they explain how aspen and maple adapt to their environments? Do they explain why maple succeeds aspen as a forest recovers from clearcutting? Do they determine aspen’s and maple’s very different roles in the food web and in the ecosystem? If you can’t sleep at night until you understand what a broken symmetry is saying, you know you have a very good natural history question by the tail. The question that has kept me awake many nights—why does a moose eat this and not that?—contains a very powerful asymmetry whose answers were not obvious when we first asked it and even today are not completely known. Seeking those answers has led us in many directions, such as investigating plant and soil chemistry, the physiology of moose energetics, how plants respond to being eaten, and the development of spatial patterns of browsing and plant distributions across the landscape. But I keep coming back to it

from new angles, each initiated by thinking about a different aspect of the natural history of moose. Right now, I am thinking about how the changes to the forest ecosystem wrought by moose browsing become selection pressures on future generations of moose.

Natural history is also a good way for children and nonscientists to enter into the scientific study of nature. It is not necessary that nonscientists and children engage in elaborate experiments or mathematical models or that they become coauthors on scientific publications. But learning how to pose a good natural history question from observations made during a walk in the woods or a day weeding the garden would add an extra dimension and enjoyment to these activities. It would also enrich children's and citizens' understanding of nature and how we do science. We desperately need informed citizens who understand nature and the practice of science, because making sound environmental policy requires that citizens who vote and policymakers who write laws have some idea of how nature works and how we find out about it. Nonetheless, the place of natural history in school and college curricula has declined drastically in recent decades.¹⁰

As we become more urban, many people, especially children,¹¹ are becoming increasingly estranged from nature. Yet natural history underlies many of today's policy and legislative issues, including global warming, the sustainable harvesting of resources, the control of predators and insects, and the preservation of species. Natural history is the underpinning to conservation,¹² to natural resource management,¹³ and to human health and food supply.¹⁴ We have learned precious little about the natural history of most organisms other than those we can harvest for money, even in biomes as well studied as the North Woods. Much, if not most, of what we know about the nonharvestable flora and nongame wildlife of any biome is the paragraph on the organism in a field guide. But how the North Woods or any other biome will respond to climate change, timber harvesting, hunting, or invasion by exotic

species depends on the details of the natural history of its constituent organisms. We need to help people re-engage a sense of delight and wonder in the natural world to address these practical problems. The natural history of where they live is probably the best place to start.

A fascination with how the world works is an important part of what it means to be a human being; the cave paintings at Chauvet testify eloquently to that.¹⁵ If we lose that fascination, we become less human. Our decisions on how we care for the earth will be enhanced if we renew this basic human trait. As Robert Michael Pyle has said, “What we know we may choose to care for. What we fail to recognize, we certainly won’t.”¹⁶ I firmly believe that if people could know, really know, what beautiful, living, working systems lakes, rivers, prairies, wetlands, beaches, and forests are, they would do everything they could to preserve them. Causing the extinction of a species or the demise of an ecosystem would then seem a crime equal to the defacing of the *Mona Lisa* or the *Pietà*. I hope this book helps people understand that.