

SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

*Ecological Restoration of Southwestern
Ponderosa Pine Forests*



ECOLOGICAL RESTORATION INSTITUTE

Edited by PETER FRIEDERICI

FOREWORD BY GARY PAUL NABHAN

Ecological Restoration of Southwestern Ponderosa Pine Forests

Edited by *Peter Friederici*

Ecological Restoration Institute at Northern Arizona University

Foreword by Gary Paul Nabhan

Society for Ecological Restoration International

ISLAND PRESS

Washington • Covelo • London

Copyright © 2003 Arizona Board of Regents

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, 1718 Connecticut Ave., NW, Suite 300, Washington, DC 20009

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

Library of Congress Cataloging-in-Publication Data

Ecological restoration of southwestern Ponderosa pine forests / Edited by Peter Friederici and Ecological Restoration Institute at Northern Arizona University ; foreword by Gary Paul Nabhan.

p. cm.

Includes bibliographical references and index.

ISBN 1-55963-652-1 (hardcover : alk. paper) — ISBN 1-55963-653-X (pbk. : alk. paper)

1. Ponderosa pine—Southwestern States. 2. Forest ecology—Southwestern States. 3. Restoration ecology—Southwestern States. I. Friederici, Peter, 1963– II. Northern Arizona University.

Ecological Restoration Institute.

SD397.P6115E36 2003

577.3'0979—dc21

2003000628

British Cataloguing-in-Publication Data available

No copyright claim is made in the work of Malchus B. Baker Jr., Gretchen Barkmann, Phil Kemp, Laura P. Moser, José F. Negrón, Barbara G. Phillips, Carolyn Hull Sieg, and G. Thomas Zimmerman, employees of the federal government.

The financial support of the United States Bureau of Land Management under BLM Grant No. PAA-01-7002 is acknowledged in making this work possible.

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

Printed on recycled, acid-free paper ♻️

09 08 07 06 05 04 03 10 9 8 7 6 5 4 3 2 1

FOREWORD

Gary Paul Nabhan

The southwestern ponderosa pine forests explored and studied by pioneering ecologists John Wesley Powell, C. Hart Merriam, and Aldo Leopold are not the same as what we see, walk through, and manage today. Although still eagerly visited for their grandeur and wildness from the rims of the Grand Canyon to the heights of Mesa Verde and the remote valleys of the Gila Wilderness, these habitats have changed, sometimes subtly and sometimes dramatically, under the influence of skewed human perception, action, and inaction.

Fortunately, a talented team of scholars and restoration practitioners—many of whom are contributors to this volume—are broadening our views of ponderosa-dominated landscapes. Central to their work is the elaboration of a functional, evolutionary theory of ecosystem health that can guide pine habitat restoration much as Darwinian biomedical theory is freshly guiding the practices of preventing and treating diseases among humans. Unless we understand the conditions our species evolved under and adapted to, our interventions to prevent or control human disease are likely to miss the mark. By the same token, we need to understand the evolutionary ecology of ponderosa pine communities if we are to effectively prevent or control massive wildfires, devastating plagues or tree diseases, and infestations by invasive species. The authors of this volume are among a new cadre of “ecosystem physicians” and “forest shamans” practicing preventative and restorative medicine on a scale of unprecedented magnitude.

Our deeper understanding of forest history is key to this endeavor. The authors of this volume are looking at that history through many different lenses, thereby seeing the ecological and social processes affecting pine habitats with a degree of precision that scientists a few decades ago could only have dreamed of. This precision comes from using a variety of micro- and

macro-lenses, rather than a single view. Native American land-use history, Anglo and Hispanic settlement history, dendrochronology, soil phytolith analyses, and ethical perspectives all give us distinctive views into the forest—and though these views may appear contradictory at first glance, they do largely complement one another. The wonderful legacy of the Ecological Restoration Institute’s efforts to understand the ponderosa forest’s reference conditions through such diverse lenses lies in how much true integration and synthesis of these varied disciplines and data sets it has been able to achieve, backed by experimental confirmation of hypothesized trends. It has carefully moved from the descriptive to the prescriptive while keeping a feedback loop between the two phases.

Writing this during a year in which more than half a million acres of ponderosa forest has burned in the region due to a tragic legacy of misperception—and in some places, mismanagement—I must underscore *how much this work ultimately matters*. It is critical to saving human lives and protecting cultural resources, from historic buildings to prehistoric heritage sites of irreplaceable value, but it is also critical to maintaining viable wildlife populations; to the furtherance of ecosystem services such as flood control, pollination, and air pollution abatement; and to the rational harvesting of timber and nontimber forest products. If this vision of ponderosa forest restoration proceeds—with modification, as new research refines our understanding of natural processes—it will lead to more habitat heterogeneity and to healthier habitats for a wide array of forest plants and animals. I cannot imagine that the health and well-being of human forest residents won’t tangibly improve as well. That the public will see the obvious, tangible links between “healthy forests” and “healthy communities”—and not a political facade that merely uses these words—is indeed our ultimate goal.

ACKNOWLEDGMENTS

This book owes its existence to the Ecological Restoration Institute at Northern Arizona University, where federally funded projects to develop and test ponderosa pine forest restoration techniques have been under way since 1995. Like this book, the ERI's work in research, application of research results, and outreach has been a collaboration among numerous people, especially the university's faculty, staff, and students. NAU president John Haeger and former president Clara Lovett deserve particular recognition for their work in establishing and strengthening the ERI. Without their support this book and much of the research and scholarship that undergird it would not have been possible.

This volume had its genesis in a research workshop conducted at NAU in February 2001, which was ably facilitated by David Bernard, Carol Murray, and Lorne Greig. The faculty, staff, and students of the Ecological Restoration Institute provided indispensable assistance throughout the process of writing and editing, especially Wally Covington, Pete Fulé, Diane Vosick, Doc Smith, Charlie Denton, Nikki Cooley, Roberta Tohannie, Lisa Machina, Dave Huffman, Jonathan Bakker, Mark Daniels, Linsey Baker, Chuck Bullington, Mary Hines, Gina Vance, and Judith Springer. Carl Fox, Claudette Piper, and Winnie Ennenga provided important logistical help and advice, as did Alan Poskanzer of Arizona State University.

The peer reviewers who read and commented on chapters contributed a great deal to this book's comprehensiveness and clarity. Along with those acknowledged in individual chapters, they included Brian Cottam, Brad Ack, Tammy Randall-Parker, Christina Flynn, Michele James, Kieran Suckling, Scott Anderson, Julio Betancourt, Patrick Pynes, Andrea Hunter, Phyllis Hogan, Taylor McKinnon, Hal Rothman, Debra Larson, Tom

Brown, Roger Blair, William R. Jordan III, Steven Davis, R. Bruce Hull, Brett KenCairn, Alan Farnsworth, Craig Allen, Steve Overby, Abe Springer, Leonard DeBano, Tom Heinlein, Gregory Aplet, Greg Taylor, Ken Moore, Tim Duck, Melissa Savage, Jonathan Bakker, Peter Ffolliott, Becky Kerns, John Randall, Scott Gillihan, Shaula Hedwall, Michael Rabe, Amy Waltz, Diana Six, R. William Mannan, Tad Theimer, Deborah Ulinski Potter, Janice Peterson, John Hanson, Linda Farnsworth, David Wilcox, Brian Nyberg, Barry Gold, and three anonymous reviewers. Janice Busco, Laura DeWald, and Norris Dodd also commented on and improved chapter drafts.

Others who contributed through provocative questions, discussion, and advice included Gary Paul Nabhan, Michele James, Stephen Germaine, John Gerritsma, David Taylor, Sharon Galbreath, and Michael Soulé. Michelle Volk, Dan Boone, Joel Viers, and Scott Curran assisted with illustrations. Sullivan/Santamaria Design created the maps. Don Falk and James Aronson of the Society for Ecological Restoration International helped shape both the book's content and form. The book's production would not have been possible at all without the tireless help of Barbara Dean and the staff at Island Press. Finally, though much of the research presented in this book has been made possible through federal funding, especially through the help of the Bureau of Land Management, the views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. government.

INTRODUCTION

Peter Friederici

It is the largest ponderosa pine (*Pinus ponderosa*) forest in the world—a swath of trees that extends from west-central New Mexico into northern Arizona, cloaking plateaus, canyons, and ridges with dark green foliage that provides a welcome respite from the arid, lower lands that surround it. And on June 18, 2002, it caught fire.

Driven by drought and high winds, what became known as the Rodeo-Chediski Fire exploded to 125,000 acres (50,000 hectares) within two days. Flames leaped hundreds of feet into the air. The smoke plume was visible from space. By the time the smoke cleared, two weeks later, the Rodeo-Chediski fire had burned more than 460,000 acres (186,000 hectares) of ponderosa pine forest, piñon-juniper woodland, and mixed conifer forest. It was the largest fire recorded in Arizona state history. Over 400 buildings had been destroyed, more than 30,000 people had been evacuated from their homes.

The fire was erratic; some areas within its perimeter retained living trees. But others—perhaps half the entire acreage—were devastated, shorn of all living vegetation. When the summer rains arrived in July, they eroded away ash and soil and washed this sediment into creeks and rivers. The areas most severely burned would not again support large, old-growth pine trees for centuries. For people living in or near the burned area, or downstream, it was a bitter reminder that human beings could not fully manage the forest to their liking.

Long needles in clumps of three, a sweet smell of vanilla and pine resin on the wind, the souging of wind in limber branches, orange-yellow bark that flakes off in puzzle-piece shapes: ponderosa pine trees are a hallmark of the American West. Ponderosa and closely related pines grow on millions of acres from the cordillera of central Mexico to southern British Columbia,

from the Sierra Nevada and the Cascade Range to the Black Hills. Nowhere do ponderosa pines more typify a region than in the southwestern states, where they grow sometimes in monotypic stands, sometimes mixed with other trees, across wide plateaus, in sheltered canyons, on steep slopes, isolated in sandstone pockets. They tower over grasses, wildflowers, and shrubs, or persevere in gnarled and stunted form on lava flows or cinder fields. Much of the material here will be of relevance to readers elsewhere in the species' broad range—or to readers seeking to restore other ecosystems—but this book focuses on the ponderosa pine forests of the Southwest.

Fire has always shaped these forests—but not fires like the Rodeo-Chediski Fire. Detailed scientific evidence in the form of tree-ring records, studies of relict sites, and reconstructions of past forest conditions shows that fires in southwestern ponderosa pine forests were very common in the centuries and millennia before European-American settlers arrived, but generally not intense. They could be large, especially during years of drought, but they burned primarily on the ground and left large trees standing. What, then, has gone wrong?

Large fires that leap from crown to crown and consume entire stands of trees certainly are a natural phenomenon in parts of the American West—in lodgepole pine forests, for example, and in many montane mixed conifer and spruce-fir forests, and perhaps in some piñon-juniper woodlands. In ponderosa pine forests, though, they are an artifact of the modern era and of human intervention. Prior to the 1960s a 50-acre (20-hectare) crown fire in a southwestern ponderosa pine forest was considered large; in the 1970s, fires of hundreds of acres grew more common; by the 1990s, some fires killed ponderosa pine stands across tens of thousands of acres. The Rodeo-Chediski Fire was a degree of magnitude larger still. It could only have become as large and as severe as it did when it did. It could only become so damaging because thousands of people had built houses in forested terrain that previously had been undeveloped. It could only become so intense because decades of human-caused changes in forest conditions had disrupted the natural recycling and population control functions of low-intensity fire by filling the forest with a heavy load of dry woody fuels.

The fire underlined the increasingly stark choice faced by those who live and work in southwestern ponderosa pine forests: we can experience numerous small fires, or few but very damaging large ones. The fire-management strategy chosen by most forest managers during most of the twentieth century—attempting to effectively eradicate fire from the forest—is untenable. There is simply too much fuel in the forests, too much dry

weather, and too many ignition sources in the form of lightning or careless or malicious people, to get rid of fire. These forests will burn whether we want them to or not. In 2002 extensive restrictions on forest access, sophisticated firefighting technology, and armies of firefighters were not enough to control the Rodeo-Chediski Fire.

We must choose, then, what sort of fire we want to have, and what sort of ecological role we want it to play. It is clear that frequent low-level fires are preferable according to virtually every indicator: they are less dangerous, preserve and maintain wildlife habitat and aesthetic values better, produce less smoke in the aggregate, result in far less erosion, and maintain ecological functioning and forest structure in ways that are less harmful to the forest as a whole. Even where they have not burned in high-intensity fires, most contemporary forests that have not experienced low-intensity fires for many decades are severely stressed. Their old trees are dying due to insect attack or competition with large numbers of young pines; their understory plant communities are impoverished due to lack of light, nutrients, and water; their faunal communities are altered.

Restoration of these forests, then, revolves around reintroducing such fires and reestablishing natural ecosystem patterns and processes. If we allow them, these fires can once again play the role they historically played in these forests, thinning out underbrush and trees, cycling nutrients, and stimulating the growth of grasses, wildflowers, and shrubs. In most circumstances, the goal of restoration is not, and cannot be, to return forests to precisely the condition they were in prior to Euro-American settlement, since some of the ecological changes that have taken place—such as species extinctions, climate change, and the introduction of noxious or invasive species—are essentially irreversible. It is, rather, to nudge their ecological trajectory so that they can return to a condition that is self-sustaining and compatible with the conditions under which their constituent organisms evolved.

Restoration acknowledges that these forests are dynamic, ever-changing places. It does not seek to turn them into museum pieces, but it does have a value system: namely, restoration is the putting into practice of the belief that most contemporary southwestern ponderosa pine forests are not healthy because they have departed too far from natural conditions, and that this lack of health has serious negative consequences for ecological functioning, for biodiversity, and for human values. Restoration lies at the heart of both good forest management and a healthy human role in the region's forests. Though it focuses on much more than prevention of severe

wildfires, it aligns well with the interest southwestern residents and decision-makers have shown in reducing fire danger in and around forest communities—as well as in the backcountry.

Restoration of these forests has extraordinary potential. Unlike many other ecosystems in need of restoration, southwestern ponderosa pine forests still cover vast acreage. Most have not undergone a type conversion to some other form of vegetation: they still are ponderosa pine forests, however altered. Most of their acreage is in public hands and is prized for recreation, aesthetics, wildlife habitat, and other values. Restoration of these forests matters deeply, and not just to ecologists.

The management of these public lands is also shaped by public desires and funded largely by public monies—and profoundly affected by a long history of contention between competing desires for resources. For these reasons, restoration can also be extraordinarily controversial. Reintroducing fire is difficult. At some level, many people still cling to Smokey Bear's blanket condemnation of all fire. Residents regularly complain about smoke when management agencies conduct prescribed burns. The forests are so full of fuel that, during dry periods, almost any fire can become a conflagration. Research has also shown that simply reintroducing fire can have effects exactly opposite those desired by restorationists, as it can kill large, old pines while leaving young ones unscathed. As a result, it is often necessary to thin forests of woody fuels by cutting younger trees that have become overly dense before fire can be safely returned—that is, to mechanically alter stand structure so that fire can play its natural role in maintaining ecosystem patterns and processes.

Mechanical treatments can be controversial. Cutting trees leaves scars that many people do not like to see; alters wildlife habitat; can cause soil compaction and erosion; and can provide an entrée for invasive species. It is labor-intensive and often expensive, and has the potential to confound ecological with economic incentives. It is the proposed cutting of trees, above all, that has made restoration extremely controversial in many places. Forest restoration, then, is not simply a matter of understanding ecology. The authors of this volume explore both the ecological reasons for and effects of restoration *and* the controversies attending it. Managers should be aware of both.

Restoration seeks to treat the *causes* of declining ecosystem health, rather than the *symptoms*. But it is no panacea. It cannot fix all the problems of our forests, and restoration in its strictest sense may not be compatible with desired resource conditions and uses in many circumstances.

It is not a one-time solution. Initial thinning and prescribed fire treatments will need to be followed by other prescribed fires, perhaps further thinning, and perhaps seeding or replanting of native vegetation or eradication of nonnative plants.

In the backcountry it may be possible to restore something like a natural fire regime, in which lightning-caused fires will be free to burn where they will at low intensities. Fragmentation and heavy development will make that impossible in many places, though. Near developed areas restoration cannot result in a hands-off management strategy, as it will likely be necessary to conduct ongoing forest maintenance through prescribed burning. Perhaps we may be able to gauge the growing maturity of our land management techniques by the extent to which we are able to align restoration practice with our other requirements of the land, keeping in mind that “cultural practices and ecological processes can be mutually reinforcing” (SER 2002).

We should also be careful about terminology. Fueled by intensive political interest and high levels of funding for fire protection and prevention, the rhetoric of forest management is rife today with jingoistic talk of “restoration” that is not *ecological* restoration. The revegetation of severely burned areas, for example, is not restoration; it is more akin to *reclamation*—an attempt to avert severe erosion of soil and ensuing degradation of the land. Such treatments do not seek to rapidly restore the structure and function of the original forest. Thinning treatments that seek only to remove some small-diameter trees in order to reduce fire danger are not restoration, for they fail to give sufficient attention to the restoration of grass and wildflower understories, the foundation of most of the biological diversity in these ecosystems. Treatments that are not linked with frequent, low-intensity burning will fail to restore what is certainly a keystone process in these ecosystems. Further, the lack of frequent fire may result in a renewed need for thinning in the future, without any of the benefits of restoration of understory vegetation. The removal of old-growth pines is emphatically not restoration, for numbers of old trees have declined throughout ponderosa pine forests. These old-growth trees are the very trees that restoration seeks to protect and reinvigorate.

Forest restoration focuses on returning low-level fire to its core role, and on protecting the oldest trees and promoting the growth and development of new generations of old trees. It also must consider other native plant species besides pine trees; it must consider restoration of native wildlife composition and densities; it must consider nutrient cycling and hydrology;

it must address concerns about invasive species. For it to succeed at meaningful landscape scales it must also be linked to work such as the removal of roads and the restoration of springs, wet meadows, and open, grassy parklands, most of which are severely degraded throughout the Southwest. Finally, if it is to become a lasting part of the social landscape, restoration must benefit and sustain human communities.

Given this complexity, it is no wonder that there has been and will continue to be a tension between those who focus on the dangers from large-scale fire and hence advocate for large-scale restoration, implemented swiftly, and those who would take a slower approach. The brakes on restoration are many. If restoration presents all the promise of a broad, interdisciplinary endeavor that uses a wide range of human capabilities, it is also—for many of the same reasons—fraught with difficulty. Residents often oppose prescribed burns. Some environmentalists, concerned about potential profiteering by a reestablished wood products industry, oppose commercial thinning treatments. Land managers face bureaucratic inertia, red tape, and litigation that can delay projects for years—sometimes for so long that conditions change sufficiently so that the entire inventory, project planning, and environmental review process becomes outdated and must be begun again, causing a lack of follow-through to implementation that stifles the creativity and flexibility needed to conduct restoration. Congress continues to appropriate far more funding for fire suppression than for restoration treatments that will ultimately (but often not immediately) reduce suppression costs. Many rural communities and workers lack the capital, equipment, and skills needed to carry out the needed work. Markets for the small-diameter timber removed from thinned forests often do not exist, necessitating public funding for thinning. This volume, by synthesizing much of what is known about key aspects of ecological restoration in ponderosa pine, may begin to address some of these problems.

How might we measure the success of restoration treatments? In addition to general guidelines given elsewhere (SER 2002) we might consider some specific criteria. In the short term, success will be measured largely by a reduced risk of large-scale high-intensity fires. In the long term, it will be measured by answers to more complex questions such as these:

- Do restoration treatments restore natural patterns and processes?
- Do they create a self-sustaining matrix?
- Do they facilitate sustainable regeneration of ponderosa pine and other plants?

- Does the resulting habitat matrix support diverse plants and wildlife within the natural range of variability?
- Do they accommodate climate shifts and changes, whether cyclical or not?

In the end, the success of forest restoration will depend on the degree to which human beings over many decades agree to work with, rather than against, the natural processes that have created these forests.

Restoration entails difficult choices, but working toward it should itself not be a difficult choice. Not implementing restoration is an option, but not a good one. As a recent book puts it, “Simply leaving today’s forests alone after a century of fire suppression and forestry focused on extraction of big trees is not caring for them; it is abandonment” (Arno and Allison-Bunnell 2002). To abandon our forests in this way will result in burned-out and depauperate landscapes that will support a less diverse array of plants and animals, and a more limited range of human uses, than today’s. To carefully conduct restoration treatments on a large scale, on the other hand, and to do so not just around human settlements but across the broader landscape, will protect ecologically important areas and help ensure that our forests provide a broad range of habitats and ecological values for generations to come. Only that management choice will be equitable to future human generations and to our forest surroundings themselves.

A few notes about this book’s scope, organization, and terminology. The region this book focuses on includes Arizona, New Mexico, and the southern portions of Utah and Colorado. The majority of the scientific research profiled here has been conducted in northern Arizona, but managers working elsewhere are also likely to find much of interest here. Indeed, restorationists working in entirely different ecosystems have faced many of the same difficulties arising from social contexts that are profiled in this book. The book is intended to become part of an evolving conversation about ecological restoration as a whole as it is carried on throughout the world.

Ecologically, though, this book is *only* about ponderosa pine forests. All too often discussions of western forest health suffer from the unwarranted lumping-together of forest types that are ecologically very different. Restoration of, say, southwestern mixed-conifer forests or piñon-juniper woodlands may well be warranted, but the scientific basis for such activities is not the same as that in this volume. Some of the general principles described may be widely applicable, but this book does not summarize information in such a way that it may be applied uncritically to other forest types.

Nor does it present a single approach at all. The book does not call for any single restoration prescription, especially not any one thinning prescription. Decisions about how to conduct restoration must always be made on a local basis. They must be based both on a scientific understanding of local ecological conditions and on consideration of other factors. Those planning and implementing restoration projects typically must consider ecological, social, and economic perspectives as they do their work. Still, this book is mainly based on ecological and natural resource science, and for that reason the limitations of science are given more consideration in the book than, say, the limitations of politics, economics, or previous forest management paradigms. Such critiques are readily available elsewhere.

The book is organized into four sections that sequentially narrow the field of restoration from the general to the specific. The first lays out the overall context—ecological, social, economic, political, and philosophical—for restoration. The contributors to this section hail from a variety of disciplines and speak with diverse voices that epitomize the diversity of views about restoration. The second section focuses on how important ecosystem processes such as fire, hydrology, and nutrient cycling are affected by restoration activities. The third section goes into detail in assessing treatment effects on such specific ecosystem components as trees, understory plants, animals, and rare or invasive species. The fourth section looks at the details of implementing restoration projects by examining such topics as smoke management, the protection of cultural resources, monitoring, and other issues. Each section is introduced with a case study that demonstrates some of the promise and pitfalls of ongoing restoration projects.

Finally, some points on terminology. The contributors generally refer to forest tracts that have been the subject of recent restoration work as “treated,” as opposed to “untreated.” Restoration is a long-term process, and a tract that has been thinned and subsequently burned once cannot yet be considered “restored”—rather, it is perhaps more appropriate to state that it has been set on a restoration trajectory. Authors also use the term “presettlement” to refer to forests as they were before the onset of Euro-American settlement—not out of any desire to deny the effects indigenous peoples had on forest structure over many years, but simply because it is less awkward than the term “pre-Euro-American settlement.” Collectively, our vision is that restoration will draw on the region’s long human history in returning forests and people to a working relationship that enriches both.

CONTENTS

FOREWORD	xi
<i>Gary Paul Nabhan</i>	
ACKNOWLEDGMENTS	xiii
INTRODUCTION	xv
<i>Peter Friederici</i>	
PART I. The Context for Restoration	1
1. The “Flagstaff Model”	7
<i>Peter Friederici</i>	
2. The Evolutionary and Historical Context	26
<i>W. Wallace Covington</i>	
3. First Peoples in the Pines: Historical Ecology of Humans and Ponderosas	48
<i>Thom Alcoze</i>	
4. Ecological and Market Economics	58
<i>P. J. Daugherty and Gary B. Snider</i>	
5. The Governance Environment: Linking Science, Citizens, and Politics	70
<i>Hanna J. Cortner</i>	
6. Ecological Restoration as Thinking Like a Forest	81
<i>Max Oelschlaeger</i>	
PART II. Restoring Ecosystem Functions and Processes	93
7. The Ponderosa Pine Forest Partnership: Ecology, Economics, and Community Involvement in Forest Restoration	99
<i>William H. Romme, Mike Preston, Dennis L. Lynch, Phil Kemp, M. Lisa Floyd, David D. Hanna, and Sam Burns</i>	

8. Fuels and Fire Behavior <i>G. Thomas Zimmerman</i>	126
9. Soils and Nutrients <i>Paul C. Selman, Adrien Elsewood, and Stephen C. Hart</i>	144
10. Hydrology <i>Malchus B. Baker Jr.</i>	161
11. Assessing Landscape-Level Influences of Forest Restoration on Animal Populations <i>James Battin and Thomas D. Sisk</i>	175
PART III. Restoring and Protecting Biological Diversity	191
12. Healing the Region of Pines: Forest Restoration in Arizona's Uinkaret Mountains <i>Peter Friederici</i>	197
13. Tree Health and Forest Structure <i>Joy Nystrom Mast</i>	215
14. Understory Vegetation <i>Julie E. Korb and Judith D. Springer</i>	233
15. Exotic Invasive Plants <i>Carolyn Hull Sieg, Barbara G. Phillips, and Laura P. Moser</i>	251
16. Vertebrates <i>Carol L. Chambers and Stephen S. Germaine</i>	268
17. Arthropod Responses: A Functional Approach <i>Karen C. Short and José F. Negrón</i>	286
18. Threatened, Endangered, and Sensitive Species <i>Paul Beier and Joyce Maschinski</i>	306
PART IV. Conducting Restoration: Practical Concerns	329
19. Community-Based Forest Restoration <i>Ann Moote</i>	335
20. Ecological Restoration in the Urban–Wildland Interface <i>John M. Marzluff and Gordon A. Bradley</i>	353
21. Air Quality and Smoke Management <i>Gretchen Barkmann</i>	371
22. Restoration and Cultural Resources <i>Helen C. Fairley</i>	387
23. Monitoring <i>Peter Z. Fulé</i>	402