

ECOLOGICAL RESTORATION

SUSAN M. GALATOWITSCH

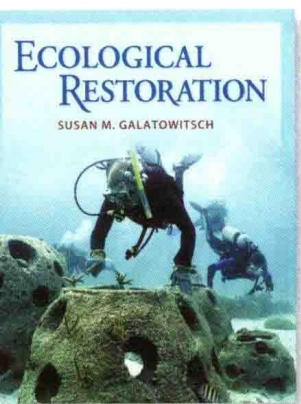


ECOLOGICAL RESTORATION

Susan M. Galatowitsch
University of Minnesota



Sinuer Associates, Inc. • Publishers
Sunderland, Massachusetts U.S.A



About the Cover

The front cover shows biologists checking coral growth on “reef balls,” which are concrete structures designed to enhance the reestablishment of reef organisms. The photographs on the back cover show other examples of techniques that have been developed for ecological restoration. (Front cover photograph courtesy of <http://www.reefball.org>.)

Ecological Restoration

Copyright © 2012. All rights reserved.

This book may not be reproduced in whole or in part without permission from the publisher.

Address editorial correspondence and orders to:

Sinauer Associates
23 Plumtree Road
Sunderland, MA 01375 U.S.A.
Fax: 413-549-1118
Email: publish@sinauer.com
Internet: www.sinauer.com

Library of Congress Cataloging-in-Publication Data

Galatowitsch, Susan M.

Ecological restoration / Susan M. Galatowitsch. -- 1st ed.
p. cm.

Includes bibliographical references and index.

ISBN 978-0-87893-607-6

1. Restoration ecology. 2. Nature--Effect of human beings on. I. Title.

QH541.15.R45G34 2012

639.9--dc23

2011046579

Printed in China

5 4 3 2 1

Ecological Restoration



This book is dedicated to the many ecological restoration professionals and community leaders who have committed years or even decades to repairing landscapes and seascapes, and the ecosystems and species within them.



Preface

To what extent can we reverse the damage caused by humans to Earth's ecosystems and species? Our potential to effectively pursue ecological restoration hinges on our knowledge and understanding of ecosystems and species, our resolve and commitment of adequate resources to do so, and our ability to be a catalyst for ecological recovery. Of course, some impacts are easier to correct than others, some places more amenable to being healed, and some causes of damage less intractable. In situations like species extinctions, human impacts are irreversible, but in many others, the limits of ecological restoration still reflect our capacity to act. Over the past few decades, there has been a concerted effort around the world to advance the science and practice of ecological restoration. And, although our capacity for ecological restoration remains much lower than our capacity to cause ecological impact, the scale, variety, and complexity of ecological restoration projects have increased substantially. Sharing what we've learned from past and ongoing restoration efforts is needed to inspire and inform others embarking on new projects and programs.

In the early 1980s ecologists and environmentalists began to develop a field of study called restoration ecology and a professional practice called ecological restoration. Since then, a body of academic literature has been developed, scientific journals established, books written, businesses started, laws passed that mandate or facilitate restoration, and programs launched in almost every part of the world to support implementation of restorations. Now commonplace, ecological restoration (or restoration ecology) classes were just starting to be offered by colleges and universities in the early 1990s. Since then, some universities have even expanded their educational opportunities to offer entire academic programs focused on preparing ecological restoration professionals. What hasn't emerged to support teaching and learning in this field is textbooks. University professors, like myself, have relied mostly on "readers" we assembled from the academic literature to introduce concepts and from regional resources to introduce practice. A couple of early books became widely used student resources, notably Jordan, Gilpin and Aber's 1990 collection of papers, *Restoration Ecology: a Synthetic Approach to Ecological Research* and Steven Whisenant's 1999 book, *Repairing Damaged Wildlands*. Many

others, though useful, have been written for researchers or for practitioners within a particular region or working on a specific kind of restoration (e.g., river restoration, prairie restoration). Given the broadening scope and rapid advancements in ecological restoration, a textbook for ecological restoration courses is crucial for students entering the field. We (instructors) want our students to have the advantages of lessons learned from past projects and to avoid pitfalls that arise when practice isn't connected to ecological principles. This textbook was written to be a resource for students who will apply this knowledge in their careers as planners, policy makers, managers, or researchers, contributing to the restoration of ecosystems and species.

To be capable ecological restoration professionals, the students we train must be knowledgeable about the ecosystems and species they work with, and be able to diagnose problems and develop and implement lasting solutions. So, building knowledge and building decision making skills for ecological restoration are both emphasized in this textbook. Ecological restoration relies on many disparate fields, such as ecology and natural resources, civil engineering, landscape architecture, geology, soil sciences, and horticulture. The aims of restorations are ecological; the methods to accomplish these aims are often modifications of practices developed for very different purposes. Similarly, the students attracted to ecological restoration courses come from many different fields. A major challenge for ecological restoration (and this textbook) is to capitalize on the strengths of being multidisciplinary. The first step towards accomplishing this is to ensure that practicing professionals, regardless of their primary field, understand a broad range of relevant concepts. So, this textbook explains many basic concepts and provides definitions, even if they might have been covered in an introductory course in one field or another.

I organized this textbook into three parts. In Part I, students are introduced to basic concepts essential for diagnosing ecological problems and to the process of planning and implementing restoration projects and programs. Part II covers the approaches used in restoration to address degradation and impacts to landform and hydrology, soil and water quality, plants, invertebrates, and vertebrates. Restoration solutions to complex problems need to be devised from sound methods related to these fundamental dimensions of ecosystems. Part III is a collection of 19 restoration cases from around the world that were chosen to illustrate the concepts and methods covered in Parts I and II. These appear as Case Highlights throughout Chapters 1–10. At the end of each chapter, there is an opportunity for students to “apply what you’ve learned,” by considering real or hypothetical dilemmas connected to one or more of the featured cases.

Restoration decision making happens in the context of the complex social and ecological realities of particular places. Because people choose to pursue ecological restoration, it is inherently value-based. That means that social context has a huge influence on practice. This textbook uses a set of real-world cases to illustrate how and why people in different cultural, social, political, and economic situations pursue ecological restoration. Each of the restoration projects featured has progressed far enough into implementation (usually a

decade or more) to reveal vexing challenges typical of most complex projects. The featured restoration projects are especially useful for students because in all cases the restoration teams have addressed the challenges they've faced by learning from what's worked and what hasn't and making adjustments, as necessary. Learning from these cases (and others like them) complements the knowledge acquired by controlled studies (i.e., experiments) that often are done outside of the context of an actual restoration. While experiments are crucial for discerning cause-and-effect relationships, learning from cases is often necessary to understanding linkages between ecological and social aspects of restorations. The restoration cases in this textbook should provide future professionals with an awareness of what is necessary for sustaining projects long enough for an ecosystem or population to be self-regenerating. It is as crucial that ecological restoration be pursued over longer time frames as they be pursued over larger spatial scales—a topic that has received much more attention.

Although ecological restoration is considered to be a socio-ecological process in this textbook, I deliberately chose not to focus on costs and economic constraints of specific approaches and projects. Why not, given that financial support is often seen as a typical limiting factor to ecological restoration? There are several reasons. First, both the relative and absolute costs of labor, goods, and services vary greatly, depending on location and how and where the project is managed. Labor costs, in particular, vary dramatically in relationship to other project costs. Second, whether a method is considered “expensive” reflects both willingness and capacity to pay. Assessing whether costs affect the feasibility of ecological restoration typically depends on local or even project-specific factors. Valuation of ecosystem services, or natural capital, is currently receiving considerable research attention and may someday be a routine part of restoration planning.

To help students learn how to effectively pursue ecological restoration, this textbook emphasizes approaches that have been demonstrated to work, rather than focusing on untested concepts and ideas. Perhaps this seems like an overly obvious point, but in a rapidly accelerating and expanding field such as ecological restoration, new ideas and new methods are launched much faster than our ability to determine whether they are worthwhile. In ecological restoration, lag times for testing and refining ideas and practices are protracted because few projects are evaluated and reported. Minimal formal evaluation also means the body of knowledge guiding ecological restoration is sometimes based on evidence from a few projects or from qualitative rather than quantitative observations. The importance and value of monitoring is a recurrent theme of this textbook, although there are still surprisingly few examples from real world restorations to serve as precedents. Much of the science contributing to ecological restoration happens in smaller scale experiments and much of the evidence of accomplishments from practice is web-based and geared for public relations. Monitoring needs to be an established part of ecological restoration so our increasingly ambitious projects can proceed with greater efficiency and with a greater likelihood of yielding self-regenerating ecosystems and populations.

Acknowledgments

Throughout the preparation of this textbook, I depended on the contributions of many colleagues—I am sincerely grateful for their support. The University of Minnesota and King’s Park and Botanic Garden (Perth, Australia) provided me with facilities and resources necessary for research and writing, and colleagues at both institutions offered much-needed insights and humor on a regular basis. The restoration cases were developed from a combination of published reports, unpublished documents, and, most importantly, knowledge from those who worked directly on the projects. Depending on the case, these project leaders provided information through phone interviews, email exchanges, shared data, documents, and images, and reviewed and commented on case drafts. With their help, I was able to visit some of these restorations during preparation of this book and I hope to visit the others in the near future. Thanks to the following people who contributed to the cases: Bill Streever (Alaska’s North Slope); Anup Joshi, Narayan Dhakal, and Bhim Gurung (Baghmara Community Forest); Riki Gunn (Carpentaria Ghost Nets Programme); Jon Day (Great Barrier Reef Marine Park); Ian Colquhoun (Jarrah Forests); Colin Miskelly and Colin Ryder (Mana Island); Jeff Lee and Bruce Wilson (Minneapolis Chain of Lakes); Beto Mesquita (Monte Pascoal-Pau Brasil Corridor Project); Peter Carrick (Namaqualand Restoration Initiative); Pauline Drobney (Neal Smith National Wildlife Refuge); Tyler Allred, Mark Holden, John Rice, and Michael Slater (Provo River); Joyce Maschinski (Sargent’s Cherry Palm); Morten Pedersen (Skjern River); John Gunn (Sudbury Barrens); Joy Zedler (Sweetwater Marsh); Chris Boland (Tasmanian Devil); Tran Triet (Tram Chim National Park); and Sam Provoost (Westhoek Nature Reserve).

Melanie Dolezal, Hans Wagner, and Mark W. Galatowitsch assisted in various ways in moving the textbook chapters from rough drafts to reviewable manuscripts. Melanie read and edited chapters prior to content review, Hans Wagner researched information gaps; Mark W. Galatowitsch researched and acquired photographs. The following individuals provided chapter reviews: James Anderson, Myla Aronson, Andrew Baldwin, Bill Bartodziej, Jeffrey Beck, Lori Biederman, Rachel Brummel, Chris Carlson, Carolyn Carr, Carla Catterall, John Chapman, Rod Chimner, Patricia Chow-Fraser, Meredith Cornett, Robert Corry, Francesca Cuthbert, Anthony D’Amato, Kingsley Dixon, Joan Ehrenfeld, Mark L. Galatowitsch, Cathy Geist, Karen Holl, Kristina Hufford, Mrill Ingram, Karen Kettenring, John Koepke, Siegy Krauss, Doug Landis, Chris Larsen, Diane Larson, Amy Lee, Jonathan Majer, Tein McDonald, Steve McKay, Melinda Moir, Stephen Murphy, Timothy New, David Pitt, Ron Reuter, Michael Samways, Rod Sayler, Donald Schloesser, Nancy Shaw, Greg Shriver, Eric Snyder, Peter Speldewinde, Juliet Stromberg, Vicky Temperton, Anne Tolvanen, Richard Toth, and Joy Zedler. Brad Karkkainen, Loren Miller, and Robert Sterner provided input on specific topics within chapters.

Thanks to everyone at Sinauer Associates whose creativity, attention to detail, skill, and understanding of teaching and learning were crucial for cre-

ating a useful and hopefully inspiring resource for students and instructors. Laura Green led the project team, Norma Roche copyedited the manuscript, David McIntyre researched and acquired photographs, Elizabeth Morales created illustrations, Christopher Small oversaw book production, Jefferson Johnson designed the book and cover, and Jen Basil-Whitaker created the page layouts for the book. Andy Sinauer provided encouragement, guidance, and a standard of excellence throughout the process.

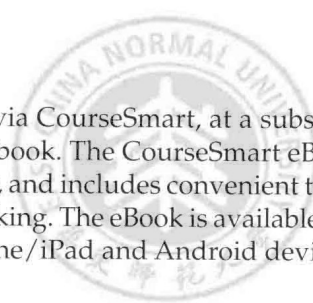
Special thanks to my husband Mark who was much more than a tireless photo researcher throughout this project; he supported this effort in numerous ways over the past two years. Lastly, I want to recognize the ecological restoration practitioners who contributed to this textbook by sharing their successes, failures, and insights. Ecological restoration can be satisfying, but it takes courage to plunge into projects that often are novel, highly visible, controversial, and/or physically very demanding. Many of the advancements in the field are due to the skilled and determined people that have undertaken ever more ambitious projects.

SUSAN M. GALATOWITSCH
UNIVERSITY of MINNESOTA
December 2011

eBOOK

www.coursesmart.com
(ISBN 978-0-87893-693-9)

Ecological Restoration is available as an eBook via CourseSmart, at a substantial discount from the price of the printed textbook. The CourseSmart eBook reproduces the look of the printed book exactly, and includes convenient tools for searching the text, highlighting, and note-taking. The eBook is available via standard Web browsers as well as on the iPhone/iPad and Android devices.



Brief Contents

- Part I Restoration Process 1**
- Chapter 1 Introduction 3
- Chapter 2 Diagnosis and Goal Setting 31
- Chapter 3 Planning 77
- Chapter 4 Social and Institutional Support 99
- Chapter 5 Monitoring and Evaluation 133
- Part II Restoration Approaches 167**
- Chapter 6 Landforms and Hydrology 169
- Chapter 7 Soil and Water Quality 229
- Chapter 8 Plants 277
- Chapter 9 Invertebrates 337
- Chapter 10 Vertebrates 373
- Part III Restoration Cases 415**
- Case A Alaska's North Slope 417
- Case B Baghmara Community Forest 425
- Case C Carpentaria Ghost Nets Programme 431
- Case D Great Barrier Reef Marine Park 437
- Case E Jarrah Forests 447
- Case F Large Blue Butterfly 455
- Case G Mana Island 461
- Case H Minneapolis Chain of Lakes 471
- Case I Monte Pascoal-Pau Brasil Corridor Project 479
- Case J Namaqualand Restoration Initiative 485
- Case K Neal Smith National Wildlife Refuge 493
- Case L Provo River 503
- Case M Sargent's Cherry Palm 513
- Case N Skjern River 521
- Case O Sudbury Barrens 527
- Case P Sweetwater Marsh 535
- Case Q Tasmanian Devil 543
- Case R Tram Chim National Park 551
- Case S Westhoek Nature Reserve 559

Contents

Part I Restoration Process 1

Chapter 1 Introduction 3

- 1.1 Human-Caused Ecological Change 4
- 1.2 The Historical Roots of Ecological Restoration 7
 - Colonial solutions for new realms* 7
 - Soil and water protection* 8
 - Restoring natural heritage* 11
 - Community-based restoration* 14
- 1.3 Defining Ecological Restoration 15
- 1.4 Motivations and Incentives for Ecological Restoration 16
 - Cultural drivers* 17
 - Economic drivers* 18
 - Demographic drivers* 20
 - Technological drivers* 21
 - Sociopolitical drivers* 22
- 1.5 Major Purposes of Ecological Restoration 24
 - Species-based restoration* 25
 - Restoration of ecosystem function* 25
 - Restoration of ecosystem services* 26
 - A comprehensive framework* 27
- Summary 28
- Apply What You've Learned 29

Chapter 2 Diagnosis and Goal Setting 31

- 2.1 Building Conceptual Ecological Models 32
- 2.2 Drivers of Ecological Change 34
 - Habitat conversion* 36
 - Pollution* 37
 - Overexploitation* 38
 - Species introductions* 40
 - Climate change* 41
 - Natural drivers* 41
- 2.3 Ecological Effects 42
 - Population declines* 44
 - Effects of habitat fragmentation* 45
 - Spread of introduced species* 48
 - Species interactions* 49
 - Disturbances and succession* 51
 - Ecosystem decline* 52
- 2.4 Assessing Current Conditions 55
 - Ecoregions* 55
 - Landscape analysis* 56
 - Site analysis* 60
 - Species analysis* 62
- 2.5 Synoptic Assessment of Ecological Resilience 64
 - Resilience and response to stress* 65
 - Resilience classification schemes* 66
- 2.6 Establishing Goals for Ecological Restoration 67
 - Approaches to goal setting* 67
 - Crafting SMART goals* 69

Goal setting for large-scale and high-risk restorations 70

Using and refining goals during the restoration process 73

Summary 73

Apply What You've Learned 74

Chapter 3 Planning 77

3.1 Components of a Restoration Plan 77

3.2 Planners and Stakeholders 79

3.3 Scope of Planning 81

3.4 Overview of the Planning Process 83

3.5 Selecting and Building Scenarios 84

Selecting scenarios 85

Building scenarios 87

3.6 Evaluating Alternative Futures 88

3.7 Investigating Restoration Techniques 90

Identifying potentially suitable techniques 90

Restoration strategies and resilience 91

3.8 Assessing the Feasibility of Proposed Restoration Plans 93

3.9 Using and Refining Plans 95

Summary 96

Apply What You've Learned 97

Chapter 4 Social and Institutional Support 99

4.1 Societal Mechanisms for Creating Restoration Opportunities 100

Legal mechanisms 100

Economic mechanisms 103

Social and behavioral mechanisms 106

4.2 Organizations Engaged in Ecological Restorations 108

Government 108

Education, business, and industry 110

Nongovernmental organizations 115

Community-based organizations 116

4.3 Establishing and Sustaining Community-Based Organizations 118

Launching a community-based organization 118

Leadership and governance 120

Financial planning and fundraising 121

Volunteers, staff, and project management 121

Collaborating with other organizations 124

4.4 Organizational Resilience 125

Situation awareness 126

Management of keystone vulnerabilities 127

Adaptive capacity 129

Summary 130

Apply What You've Learned 132

Chapter 5 Monitoring and Evaluation 133

5.1 Adaptive Management 134

5.2 Choosing Monitoring Parameters 139

5.3 Monitoring Protocols 145

Data collection methods 145

Timing, frequency, and duration 146

Spatial issues 148

5.4 Interpreting Monitoring Data 153

Comparisons to reference sites 153

Data analysis 155

Using data for decision making 156

5.5 Managing Project Records and Monitoring Data Sets 158

Case histories 160

Data management 160

5.6 Planning Monitoring Logistics 161

Summary 163

Apply What You've Learned 164

Part II Restoration Approaches 167

Chapter 6 Landforms and Hydrology 169

6.1 Wind 171

Wind-shaped landforms 171

Human alterations to aeolian processes 172

Restoration of wind-eroded landscapes 174

6.2 Surface Runoff and Erosion 177

Water movement through landscapes 178

Human alterations to surface runoff 180

Restoration approaches for reducing surface runoff and soil erosion 182

6.3 Groundwater 187

Groundwater movement 187

Human alterations to groundwater supplies 188

Restoration of groundwater flow systems 189

6.4 Inland Wetland and Lake Hydrology 191

Hydrology of wetlands and lakes 192

Human alterations to wetland hydrology 194

Restoration of wetland hydrology 196

6.5 River Hydrology and Landforms 201

Processes that shape rivers 202

Human alterations to river landforms and hydrology 207

Restoration approaches for rivers 209

6.6 Estuarine and Marine Environments 216

Landforms and hydrology in coastal environments 216

Human alterations to coastal landforms and hydrology 218

Restoration of estuarine and marine landforms and hydrology 220

6.7 Monitoring Landform and Hydrologic Change in Response to Restoration Action 223

Summary 225

Apply What You've Learned 227

Chapter 7 Soil and Water Quality 229

7.1 The Critical Zone 230

Environments within the critical zone 230

Biogeochemical cycles 231

Biota in the critical zone 233

Human-caused changes to biogeochemical cycles 235

7.2 Rebuilding Impoverished Soils 244

Soil recovery and revegetation 246

Topsoil handling and application 247

Accelerating soil development 248

7.3 Reducing Nutrient Levels in Overenriched Soils 251

7.4 Remediating Toxic Soils 252

Contaminant sources 253

Treatments for soil acidity and salinity 255

Treatments for metals and organic toxins 256

7.5 Wetlands for Wastewater Treatment 258

7.6 Reversing Eutrophication in Aquatic Systems 261

Eutrophication in marine and coastal ecosystems 261

Eutrophication in freshwater lakes and rivers 263

7.7 Remediating Toxins in Surface Waters 264

Treatments for acidity and metals 265

Treatments for oil spills 267

7.8 Monitoring Changes in Water and Soil Quality 268

Monitoring water quality 269

Monitoring soil quality 271

Summary 273

Apply What You've Learned 275

Chapter 8 Plants 277

8.1 Facilitating Natural Recolonization 278

Propagule sources for natural recolonization 279

Promoting establishment 282

Nurse plants and catalysts 284

Limitations of natural recolonization 285

8.2 Invasive Plant Control 286

Landscape-level invasive plant control 289

Site-based invasive plant control 290

Herbicide use in ecological restoration 292

Devising and implementing an invasive plant control strategy 295

8.3 General Considerations for Planting and Seeding 296

Species selection 297

Plants or seeds? 299

Sources of seeds and plants 300

Cultivar use in ecological restoration 303

8.4 Using Seeds for Revegetation 305

Seeds in topsoil transfers 305

Designing seed mixes 306

Seeding rates 307

Seed collecting 308

Seed cleaning and storage 310

Dormancy and germination 311

Seed quality 312

Seeding methods 313

8.5 Using Plants for Revegetation 314

Nursery-produced plants 315

Vegetative transplants 317

Planting plans 318

Plant installation 321

8.6 Restoring Microbial Mutualists 322

8.7 Establishing and Managing Plant Communities 325

8.8 Monitoring Restored Plant Communities and Populations 327

Summary 332

Apply What You've Learned 334

Chapter 9 Invertebrates 337

9.1 Invertebrate Habitat 338

9.2 Selecting Focal Invertebrates 341

9.3 Habitat Restoration 344

Habitat structure 344

Habitat heterogeneity 347

Landscape-scale stressors 349

Single-species considerations 352

9.4 Nontarget Impacts of Restoration Actions on Invertebrates 353

9.5 Control of Introduced Invertebrates 354

9.6 Invertebrate Species Translocations 356

Establishing a rationale for translocations 356

Founding populations 357

Releases 361

- 9.7 Management of Invertebrate Habitat 364
- 9.8 Monitoring Invertebrates in Restored Ecosystems 366
- Summary 368
- Apply What You've Learned 371

Chapter 10 Vertebrates 373

- 10.1 Selecting Focal Vertebrates 374
- 10.2 Reducing Effects of Fragmentation and Lost Connectivity 377
- 10.3 Site-Based Habitat Restoration 380
- 10.4 Curbing Overexploitation 385
- 10.5 Manipulating Trophic Interactions 389
- 10.6 Controlling Introduced Vertebrates 390
- Eradication versus reduction* 390
- Physical methods* 392
- Chemical methods* 393
- Biological methods* 394
- Devising a control program* 395
- Unexpected consequences of invasive vertebrate control* 395
- 10.7 Vertebrate Species Translocations 397
- Translocation assessment and planning* 397
- Source populations* 399
- Captive breeding* 401
- Releases* 405
- 10.8 Monitoring Vertebrates in Restored Ecosystems 409
- Summary 412
- Apply What You've Learned 414

Part III Restoration Cases 415

- Case A** Alaska's North Slope 417
- Case B** Baghmara Community Forest 425
- Case C** Carpentaria Ghost Nets Programme 431
- Case D** Great Barrier Reef Marine Park 437
- Case E** Jarrah Forests 447
- Case F** Large Blue Butterfly 455
- Case G** Mana Island 461
- Case H** Minneapolis Chain of Lakes 471
- Case I** Monte Pascoal-Pau Brasil Corridor Project 479
- Case J** Namaqualand Restoration Initiative 485
- Case K** Neal Smith National Wildlife Refuge 493
- Case L** Provo River 503
- Case M** Sargent's Cherry Palm 513
- Case N** Skjern River 521

Case O Sudbury Barrens 527

Case P Sweetwater Marsh 535

Case Q Tasmanian Devil 543

Case R Tram Chim National
Park 551

Case S Westhoek Nature
Reserve 559

Illustration Credits 569

Glossary 571

References 581

Index 603

