Stefan Zerbe

Restoration of Ecosystems – Bridging Nature and Humans

A Transdisciplinary Approach

Springer Spektrum

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The more clearly we can focus our attention on the wonders and realities of the universe about us, the less taste we shall have for destruction.

(Rachel Carson, April 1952)

Dedicated to my children

Preface

In 2022, the "Earth Overshoot Day," which indicates the date when humanity has exhausted nature's budget for the whole year, fell on July 28th (Global Footprint Network 2022). Accordingly, this day has moved forward by about three weeks compared to 2020, thus indicating increasing, unsustainable resource consumption. One may argue about this approach, the data basis, and about the determination of an exact day. What is an undisputable scientific fact, however, is the overexploitation of our natural resources and natural capital, respectively, by the world's human population and the subsequent trade-offs for the earth's ecosystems, land-use systems, and the socio-economic conditions of the societies. Worldwide, these are, in particular, the loss of biodiversity, climate change, problems of water supply, not only quantitatively but also qualitatively in terms of eutrophication and pollution, the pollution of marine ecosystems, soil erosion, soil salinization with decreasing agricultural productivity, and desertification in arid and semi-arid regions and all this related to the growth of the world's population, increasing energy demand, and the intensification of land-use and thus continuously increasing resource consumption.

The fact that renewable natural resources should only be consumed to an extent that they can regenerate is not new and has already been practiced in some indigenous human populations since millennia to ensure their permanent livelihood (Diamond 2011). However, at the latest with the book *The Limits to Growth,* the Club of Rome (Meadows et al. 1972) insistently drew attention to the fact that certain natural resources cannot be regenerated and are therefore finite. Already 25 years ago, Daily (1995) pointed out that about 45% of the world's land surface had a reduced capacity for land-use which means it was more or less anthropogenically degraded. She identified unsustainable land management as one major reason. This continuous degradation of many land-use types has been ecologically and economically quantified during recent decades, as illustrated in this book.

The current discussion on the decline of insects (e.g., NEFO 2017; "Insektensterben"), for example, shows that, despite decades of environmental policy, the establishment of legal frameworks and international conventions, and the practice of nature conservation, the desired goals of nature conservation or environmental protection in Central Europe have hardly been achieved. Even if one does not want to follow this agitated terminology such as, "forest dieback" ("Waldsterben" during the 1980s and 1990s) and "insect dieback," one cannot ignore the facts of the associated environmental problems and the urgent need for solutions. Apart from the local decline of forest stands due to high air pollution during the past decades (e.g., in the high altitudes of the Erzgebirge), the discussion about "forest dieback" has considerably stimulated forest ecosystem research in Central Europe and thus an increase in knowledge about the functions and services of our forest ecosystems. Consequently, also the discussion on "insect dieback" cannot be dismissed as mere emotional "hype." The study by Hallmann et al. (2017), which found a decline in the biomass of flying insects of around 75% over the past 27 years for various habitat types, is just one of many scientific studies that document qualitatively and quantitatively the continuous and worldwide loss of species and biodiversity, respectively, and thus the loss of important ecosystem services.

Against this background, we must raise the question of how we can use natural resources more sustainably in the future, on the one hand, and how we can restore those resources or natural capital that have already been exploited or declined, on the other. The restoration of ecosystems, based on the scientific discipline of restoration ecology, offers one of the possible answers to this. While the practice of ecosystem restoration is as old as human settlements on earth, restoration ecology has been established as a sub-discipline of ecology since the second half of the twentieth century and, since then, has developed rapidly. Today, ecosystem restoration is based on several decades of scientific research and practical experiences. Consequently, restoration ecology provides a comprehensive and valuable body of knowledge for the practice of sustainable land-use, landscape management, and nature conservation. As this book demonstrates, there is no lack of data and facts on the state of many ecosystems and land-use systems in Central Europe, respectively, nor of concepts and tools for the assessment of this state and deriving recommendations for the practice of ecosystem restoration. Nevertheless, in many cases we are still far from having achieved the desired goals of restoring functioning ecosystems and sustainable land-use with the concepts and measures of ecosystem restoration within the set time-frames. When ecosystems are even "restored" by the application of pesticides, burning vegetation, or by completely removing topsoil and vegetation, one might sometimes be willing to protect these ecosystems from those "ecosystem restorationists."

This interdisciplinary textbook will present the scientific basics of restoration ecology in an introductory section. Reasons and motivations for the restoration of ecosystems as well as reference systems will be outlined. The various measures of ecosystem restoration will be presented in the first overview. Then, those measures will be specified in more detail using the examples of the diverse ecosystems and land-use types of Central Europe. The ecosystems and land-use types are briefly introduced regarding their land-use history and ecological site conditions. Their ecosystem services are highlighted, particularly those which have been lost through overexploitation and degradation. Then, the current scientific restoration knowledge and practical experiences regarding the particular ecosystems and land-use systems, respectively, are presented. The brief outline of the land-use history of near-natural ecosystems and land-use systems of the cultural landscape is indispensable for the identification of restoration goals and respective reference systems. This follows the premise that only with the knowledge of the historical, anthropogenic impact the current ecological state can be comprehensively assessed and recommendations for the practice of sustainable land-use can be derived.

Although the practice of ecosystem restoration is essentially based on the concepts and knowledge of restoration ecology, it can only be successful if it is integrated into an interdisciplinary and transdisciplinary context, respectively. Accordingly, considerations of environmental economics as well as environmental ethics, sociology, anthropology, and religious aspects must be taken into account. These aspects will be addressed in Part III of this textbook. The penetration of a natural scientist into human science disciplines bears a risk. The expert of the respective human and social science discipline, respectively, may stumble over terms, modes of argumentation, and a lack of thoroughness in his or her respective discipline. Nevertheless, this is precisely what is intended to bridge the natural and the social sciences in order to stimulate further discussions and to intensify the scientific discourse between the natural and social sciences. This is particularly needed for the solution of the global environmental problems and the joint development of strategies to adapt to and mitigate global change. By stepping out of his or her own scientific discipline in order to investigate and understand both the ecological and human dimension of environmental problems and to develop possible solutions, the scientist enters the field of a transdisciplinarity (► Chap. 22). Consequently, this textbook follows a transdisciplinary approach.

The geographical focus of this textbook is on Central Europe, including the Alps, essentially with the countries Germany, Austria, Poland, Switzerland, Slovakia, and the Czech Republic. Thus, the most important ecosystems and land-use types are addressed for this geographical area. Forests, rivers including their floodplains, lakes, peatland, and alpine grasslands as natural or near-natural ecosystems are considered as well as the anthropogenic land-use types grassland, heaths, arable land, agroforestry systems, quarries, and settlement areas. Nevertheless, a comprehensive insight into restoration ecology and the practice of ecosystem restoration would fall short if concepts and experiences from other regions of Europe or the world were neglected. For example, a chapter on the restoration of coastal salt grassland would be incomplete without the numerous studies and experiences from Great Britain. The same applies, for example, to the extensive research and practical experiences on the restoration of heathland on the British Islands, in Scandinavia, and the Netherlands. Consequently, by considering scientific literature from whole Europe, an attempt is made to draw a comprehensive, up-to-date picture of restoration ecology and ecosystem restoration, respectively.

The numerous literature references may be a hindrance to the flow of reading. However, this is necessary to demonstrate that a huge amount of data and facts relevant to the restoration of ecosystems have already been elaborated by scientific research. In addition, these references should enable the reader to deepen specific issues, also in light of the fact that data and facts can be interpreted in different ways. In the individual chapters, key terms are highlighted in bold. Case studies from the practice of restoration are presented for the respective ecosystem or land-use type. Those case studies not only reflect successful restoration projects but are also intended to highlight problems in practical ecosystem restoration. There should be no doubt that the selection of case studies has a subjective character, but it usually follows the criteria of a comprehensive documentation of the restoration process from planning to implementation and success control, including socio-economic aspects, such as costs and acceptance. Many of the case studies presented here can also be considered examples of best practice.

This book was written in substantial parts during a sabbatical generously granted to me by the Free University of Bozen-Bolzano (South Tyrol, Italy). During this year, I was warmly welcomed by various hosts to whom I am grateful, namely (in chronological order) the Peria family on the Italian island of Elba, Prof. Dr. Ana Bozena Sabogal Dunin Borkowski De Alegria at the Pontificia Universidad Católica del Perú in Lima (Peru), David Unger in Cobán (Guatemala), Luz Marina Delgado in San Marcos (Guatemala), Prof. Dr. Victoriano Ramón Vallejo Calzada at the University of Barcelona and at the Center for Mediterranean Environmental Studies in Valencia (Spain), and Prof. Dr. Ingo Kowarik at the Technical University of Berlin. During this time, I was inspired by discussions with numerous people and colleagues, to whom I would also like to express my gratitude.

For the review of particular chapters and suggestions for their improvement, I would like to thank (in alphabetical order) Prof. Dr. Christian Ammer (University of Göttingen, Germany) for ► Chap. 7, Dr. Arthur Brande (TU Berlin, Germany) for ► Chap. 8, Dr. Ralf Döring (Thünen Institute of Sea Fisheries, Germany) for

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Stefan Zerbe
Berlin, Germany
March 2022

Reference

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I Fundamentals

About the Author

Stefan Zerbe

Professor of Environment and Applied Botany at the Free University of Bozen-Bolzano in South Tyrol (Italy)

Stefan Zerbe studied biology at the Universities of Würzburg and Stuttgart-Hohenheim in Germany, specializing in vegetation ecology. He was a research assistant at the University of Würzburg and the Technical University of Berlin, where he received his doctorate in 1992. In 1998, he was awarded his habilitation in botany. He performed research and university teaching at the Institute of Ecology at the TU Berlin until 2005. After a guest professorship in biology and botany at the TU Berlin, he took the Chair of Geobotany and Landscape Ecology at the University of Greifswald in 2005, where he also became the Managing Director of the Institute of Botany and Landscape Ecology. In 2009, he followed a direct call to the Free University of Bozen-Bolzano in South Tyrol as a professor for Environment and Applied Botany.

Stefan Zerbe developed and implemented two international Master's programs, i.e., Landscape Ecology and Nature Conservation (LENC) at the University of Greifswald and Environmental Management of Mountain Areas (EMMA) at the Free University of Bozen-Bolzano. Numerous disciplinary and interdisciplinary research projects and cooperations on the national and international level have resulted in more than 300 scientific publications, book contributions, and monographs. In addition to a wide range of other interests and topics in research and teaching, Stefan Zerbe has been working on restoration ecology and the restoration of ecosystems since his doctoral thesis on the vegetation of Norway spruce monocultures and their conversion to mixed broad-leaved forests by integrating natural ecological processes. This textbook is, therefore, both a synthesis of the current state of knowledge in an inter- and transdisciplinary perspective as well as a reflection of the author's own research work and experiences regarding sustainable land use, environmental protection, and resource efficiency.

Fundamentals

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Introduction to Restoration Ecology

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Ecosystem restoration has become an increasing challenge worldwide in recent decades to counteract the loss of ecosystem services and to restore natural resources and natural capital at the local, regional, and global level (Aronson et al. 2007; Jackson and Hobbs 2009; Zerbe et al. 2009). There is a comprehensive scientific basis and many decades of practice in ecosystem restoration. Restoration ecology, as a sub-discipline of ecology and landscape ecology, respectively, has made a considerable contribution to this (see overview of textbooks in ◘ Table 1.1). However, there is also consenst today that an

◘ **Table 1.1** Selection of thematically and geographically comprehensive textbooks on restoration ecology and ecosystem restoration from 1980 to 2022, arranged chronologically by the year of publication

Authors	Year	Book title
Bradshaw and Chadwick	1980	*The Restoration of Land: The Ecology and Reclamation of Derelict and Degraded Land*
Jordan III et al.	1987	*Restoration Ecology: A Synthetic Approach to Ecological Research*
Berger	1990	*Environmental Restoration: Science and Strategies for Restoring the Earth*
Baldwin et al.	1994	*Beyond Preservation: Restoring and Inventing Landscapes*
Harris et al.	1996	*Land Restoration and Reclamation, Principles and Practice*
Elliot	1997	*Faking Nature: Ethics of Environmental Restoration*
Rana	1998	*Damaged Ecosystems and Restoration*
Harker et al.	1999	*Landscape Restoration Handbook*
Bradshaw	2000	*Methods in Ecological Restoration*
Gobster and Hull	2000	*Restoring nature: Perspectives from the Social Sciences and Humanities*
Throop	2000	*Environmental Restoration: Ethics, Theory, and Practice*
Urbanska et al.	2000	*Restoration Ecology and Sustainable Development*
Perrow and Davy	2002	*Handbook of Ecological Restoration: Restoration in Practice*
Mitsch and Jørgensen	2003	*Ecological Engineering and Ecosystem Restoration*
Higgs	2003	*Nature by Design: People, Natural Process, and Ecological Restoration*
Wong and Bradshaw	2003	*The Restoration and Management of Derelict Land: Modern Approaches*
Temperton et al.	2004	*Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Practice*
Egan and Howell	2005	*The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*
Falk et al.	2006	*Foundations of Restoration Ecology*
Friederici	2006	*Nature's Restoration: People and Places on the Front Lines of Conservation*
Aronson et al.	2007	*Restoring Natural Capital: Science, Business, and Practice*
Boyce et al.	2007	*Reclaiming Nature: Environmental Justice and Ecological Restoration*
Naveh	2007	*Transdisciplinary Challenges in Landscape Ecology and Restoration Ecology – An Anthology*

Table 1.1 (continued)

Authors	Year	Book title
Walker et al.	2007	*Linking Restoration and Ecological Succession*
Hobbs and Suding	2008	*New Models for Ecosystem Dynamics and Restoration*
Lennartz	2008	*Renaturierung: Programmatik und Effektivitätsmessung*
Perrow and Davy	2008	*Handbook of Ecological Restoration: Principles of Restoration*
Morrison	2009	*Restoring Wildlife: Ecological Concepts and Practice of Applications*
Pardue and Olvera	2009	*Ecological Restoration*
Zerbe and Wiegleb	2009	*Renaturierung von Ökosystemen in Mitteleuropa*
Brown et al.	2010	*Sustainable Land Development and Restoration: Decision Consequence Analysis*
Comín	2010	*Ecological Restoration: A Global Challenge*
Tongway and Ludwig	2010	*Restoring Disturbed Landscapes: Putting Principles into Practice*
Egan et al.	2011	*Human Dimensions of Ecological Restoration: Integrating Science, Nature, and Culture*
Greipsson	2011	*Restoration Ecology*
Jordan III and Lubick	2011	*Making Nature Whole: A History of Ecological Restoration*
Allison	2012	*Ecological Restoration and Environmental Change: Renewing Damaged Ecosystems*
Andel and Aronson	2012	*Restoration Ecology: The New Frontier*
Galatowitsch	2012	*Ecological Restoration*
Howell et al.	2012	*Introduction to Restoration Ecology*
Prasad	2012	*Restoration and Conservation Ecology*
Carmen Santa-Regina and Santa-Regina	2013	*Restoration and Ecosystem Consequences of Changing Biodiversity*
Clewell and Aronson	2013	*Ecological Restoration: Principles, Values, and Structure of an Emerging Profession*
Van Wieren	2013	*Restored to Earth: Christianity, Environmental Ethics, and Ecological Restoration*
Rieger et al.	2014	*Project Planning and Management for Ecological Restoration*
Simonis et al.	2014	*Re-Naturierung: Gesellschaft im Einklang mit der Natur*
Chabay et al.	2015	*Land Restoration: Reclaiming Landscapes for a Sustainable Future*
Pereira and Navarro	2015	*Rewilding European Landscapes*
Palmer et al.	2016	*Foundations of Restoration Ecology*
Squires	2016	*Ecological Restoration: Global Challenges, Social Aspects, and Environmental Benefits*
Telesetsky et al.	2016	*Ecological Restoration in International Environmental Law*

(continued)

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Table 1.1 (continued)

Authors	Year	Book title
Allison and Murphy	2017	*Routledge Handbook of Ecological and Environmental Restoration*
Zerbe	2019	*Renaturierung von Ökosystemen im Spannungsfeld von Mensch und Umwelt*
Akhtar-Khavari and Richardson	2019	*Ecological restoration law. Concepts and case studies*
Kollmann et al.	2019	*Renaturierungsökologie*
Holl	2020	*Primer of ecological restoration*
Zerbe	2022	*Restoration of multifunctional cultural landscapes. Merging tradition and innovation for a sustainable future*

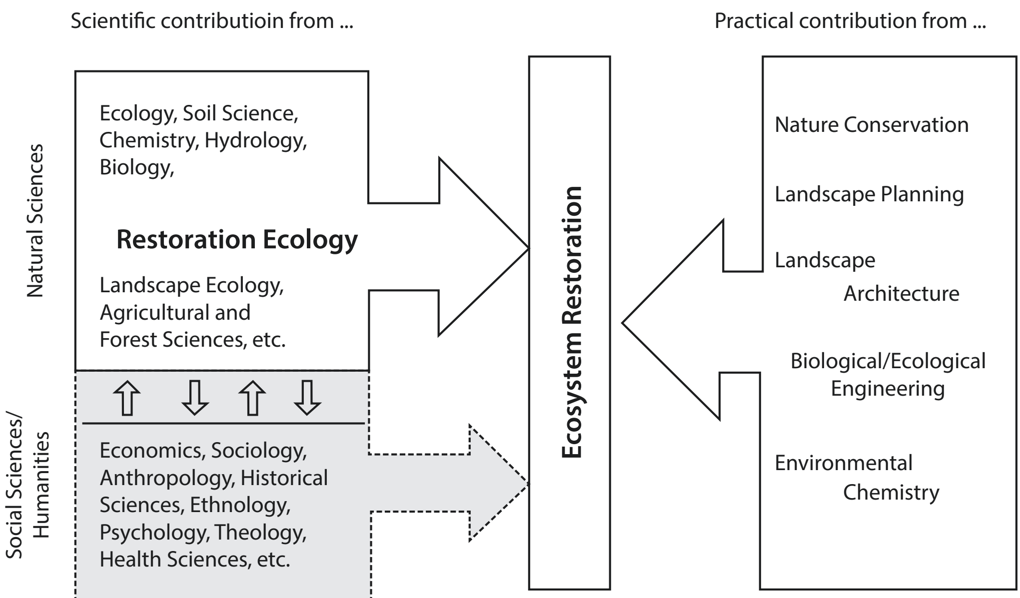
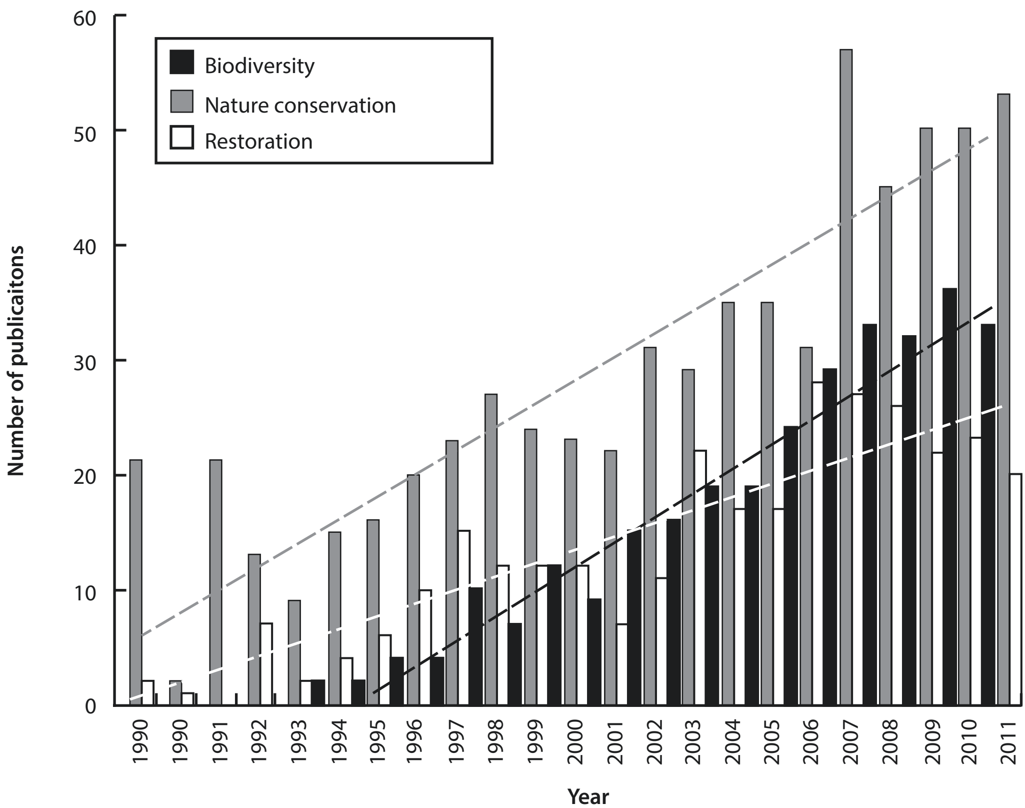


Fig. 1.1 The practice of ecosystem restoration in an interdisciplinary context, scientifically supported by the natural as well as the social sciences and humanities, respectively, and with practical contributions from applied research in various disciplines. The illustrated overlap of the natural sciences with the social sciences and humanities is intended to highlight the transdisciplinary character of restoration ecology

ecosystem or land-use type with its specific ecosystem services can only be successfully restored if not only ecological principles and fundamentals are taken into account, but ecosystem restoration is also embedded in a socio-economic context (Cairns and Heckman 1996; Higgs 1997; Gobster and Hull 2000; Throop 2000; van Diggelen et al. 2001; Aronson et al. 2007; Egan et al. 2011; Squires 2016). The practice of ecosystem restoration is thus interacting with numerous other scientific disciplines and their implications for practice (Fig. 1.1). Restoring functioning ecosystems with their services on a former industrial site in an urban area, for example, especially if elaborate measures are applied, needs a cost calculation as well as the integration of stakeholders and decision-makers. Restoration ecology becomes transdisciplinary when it applies concepts and methodologies of the social sciences and humanities, respectively, or "goes beyond traditional system boundaries" (Rentz 2004, p. 150) to solve complex environmental problems (see Mittelstrass 2011; Bernstein 2015; on Mode 1 of transdisciplinarity, see Scholz 2011; Scholz and Steiner 2015a; ► Sect. 22.4).

One of the main drivers or justifications for ecosystem restoration is considered to be the loss and restoration of **biodiversity** at the species (including genetic diversity), ecosystem, and landscape level. This is highlighted repeatedly in review studies, for example for heathlands (◘ Fig. 1.2) and peatlands (Bonnett et al. 2009). There is no doubt that biodiversity loss is a global environmental problem that has been pointed out by science and the practice of nature conservation for decades (e.g., Ehrlich 1994; Tilman et al. 1994; Pimm et al. 1995; Sala et al. 2000; Barthlott et al. 2008/2009; Cardinale et al. 2012; Hooper et al. 2012) and has been translated into environmental policies and actions in many countries around the world, at least since the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. Nevertheless, the focus of ecosystem restoration on the conservation and restoration of biodiversity falls short if the entire **ecosystem services** (► Sect. 1.3) are not comprehensively integrated into a qualitative and quantitative assessment against the background of **sustainability** (► Chap. 24).



◘ **Fig. 1.2** Scientific publications on heathlands with a focus on biodiversity, conservation, and restoration in the period 1900–2011. (After Fagúndez 2013)

First, this chapter presents important fundamentals of restoration ecology that are indispensable as a scientific basis for the following chapters. A brief historical overview of ecosystem restoration and restoration ecology is given. Basic ecological terms and key concepts are explained, which provide the scientific basis for the practice of ecosystem restoration. In particular, the concept of ecosystem services is addressed and the term degradation is discussed. An up-to-date definition of ecosystem restoration is derived from the current state of knowledge. Finally, this chapter outlines the different scales of ecosystem and landscape restoration.

Part I of this book focuses on aspects of the natural sciences, and Part II bridges the gap to the social sciences and humanities, respectively, and their implications for ecosystem restoration.

1.1 Ecosystem Restoration and Restoration Ecology From a Historical Perspective

The "restoration" of ecosystems is as old and common as man started to create settlements and perform agriculture, i.e., in principle it goes back to the Neolithic Period, for nothing other than a type of restoration is **fallow** on cultivated agricultural land, where abiotic resources regenerate. As the brief outline of the history of agriculture in ► Chap. 17 shows, fallow in the traditional three-field agricultural system only came to an end when mineral fertilizer was introduced, thus allowing for an increase in agricultural yields through a permanent nutrient supply.

One of the largest and most comprehensive restoration projects in Central Europe was the **afforestation** of the open cultural landscape with coniferous trees about 200 years ago, after a period of overexploitation of the timber resources. Grazing, forest clearance, litter gathering, and other uses that depleted the natural abiotic and biotic resources had led to a large-scale loss of forests and thus of timber as a natural resource. Woodland had been largely vanished in many regions, and heathland and poor grassland covered large parts of Central Europe. The afforestation, especially with Scots pine in the lowlands and Norway spruce in the mountain ranges, particularly since the end of the eighteenth century, also marked the beginning of regulated forestry (► Chap. 7) and the concept of sustainability (► Chap. 24).

Still without the theoretical foundations of modern restoration ecology, overused and degraded sites had already been restored since the beginning of the last century. For example, the neo-baroque **Körnerpark** in Neukölln (Berlin) was created between 1912 and 1916 as a recultivation measure on the site of a former gravel pit. The high significance of this park today in terms of ecosystem services in one of the most densely populated districts of Berlin (Statistical Report 2016 for Neukölln: 14,295 inhabitants per km^2) is easily revealed to the visitor by the number of people there on a summer day (◘ Fig. 1.3).

Experiences in ecosystem restoration through several decades are available, particularly for rivers, peatlands, lakes, and the large-scale open-cast lignite mining landscapes. Restoration ecology has developed

◘ **Fig. 1.3** The Körnerpark in Berlin-Neukölln, created in the early twentieth century as the recultivation of a former gravel pit. (S. Zerbe, August 2017) conceptually and methodologically from all these different experiences in the various ecosystems and land-use types, respectively. The restoration of the characteristic prairies in North America since the 1930s are regarded as internationally trend-setting for the development of restoration ecology. In this context, the restoration of the **Curtis Prairie** of the University of Wisconsin-Madison Arboretum is considered as one of the first initiatives (Sperry 1983; Cottam 1987; Wegener et al. 2008), even though this was not a scientifically documented experiment of restoration ecology (Anderson 2009) and has more the character of a founding myth of restoration ecology (Jordan III and Lubick 2011, p. 75). Looking at Central Europe, the first targeted attempts to restore ecosystems on a scientific basis also start during this period. If we disregard the first initiatives before 1920, more extensive recultivation measures with afforestation began in the **lignite mining area** of North Rhine-Westphalia between 1920 and 1945 (Schölmerich 2013). Today, these afforestations, some of which are very close to nature and represent interesting experimental areas of forest restoration, are already more than 80 years old (► Chap. 7). Also, there are ecological studies on mining spoil heaps. In the 1960s, for example, Bornkamm (1985) established permanent plots for the investigation of vegetation development and natural re-colonization processes on the dumping sites of opencast lignite mining.

Conceptually already well rooted in the natural sciences (e.g., biology, ecology, hydrology), **lake restoration** projects have been carried out e.g., in Sweden (Björk 2014) since the 1960s. The restoration of **peatlands** and **rivers** with their **floodplains** also has a long history of practical experience (e.g., Brülisauer and Klötzli 1998; Succow and Joosten 2001; Jürging 2006). Since the 1990s, the forestry sector in many German states has been promoting **forest conversion** and thus the restoration of near-natural forests with silvicultural programmes based on nature conservation and ecological principles. Apart from these near-natural ecosystems, the focus today is on the one hand on traditional land-use systems of the cultural landscape, such as meadows, pastures, dry grasslands, and heaths, and on the other hand on highly disturbed landscapes such as mining sites (e.g., brown coal), military training areas, and urban-industrial sites. In addition to a large number of local and small-scale restoration projects, which are unfortunately often insufficiently documented scientifically, large-scale restoration projects, in particular, have provided an impetus for the development of restoration ecology. For example, many of the large-scale nature conservation projects funded by the German government, with a total area of all projects funded to date of approximately 3700 km^2 (◘ Fig. 1.4), encompass habitat restoration (Doerpinghaus and Bruker 2016).

Similar to what Jordan III and Lubick (2011) have published with a focus on North America, it would certainly also be worthwhile to comprehensively review the history of restoration ecology and ecosystem restoration in Central Europe, also integrating the interactions of the natural and human sciences as well as the interdisciplinary impulses that result from this interaction of the various scientific disciplines.

For the development of restoration ecology as a sub-discipline of ecology, the foundation of the **Society for Ecological Restoration** (SER) in 1987 must be considered an international milestone. The society comprises representatives from science and practice and offers a platform for the exchange of information with regular international conferences. In addition, SER publishes a Newsletter that provides information on current activities in research, teaching, and restoration practice ► (► www.ser.org). In comparison to these international activities, a working group on restoration ecology was founded 10 years later in 1997 within the **Society for Ecology** (*Gesellschaft für Ökologie*), which formed the joint Working

Fig. 1.4 Completed and ongoing large-scale nature conservation projects in Germany (state: 1st July, 2016); many of these projects aim at habitat restoration. (From Doerpinghaus and Bruker 2016)

Group on Nature Conservation and Restoration Ecology in 2016.

In addition to the scientific journal *Restoration Ecology,* which is published by SER, other international scientific journals also focus on restoration ecology and ecosystem restoration, such as Environmental Management, Ecological Restoration, Ecological Engineering, Land Degradation and Development, Landscape and Ecological Engineering, Restoration & Management Notes, and Ecological Management & Restoration. Many English- and German-language journals for science and practice, including those in the disciplines of ecology, animal ecology, vegetation ecology, landscape ecology, ecological engineering, agriculture and forestry, and environmental sciences, increasingly report on ecosystem restoration projects and experimental restoration studies *sensu latu* (see Ormerod 2003; Fagúndez 2013). Since the 1980s, comprehensive textbooks with different thematic and geographical focuses have been published continuously (◘ Table 1.1).

Information on practical restoration projects is also provided by the financial sponsors of the projects (▶ Chap. 23), such as the European Union, nature conservation associations, foundations (e.g., Deutsche Bundesstiftung Umwelt, Michael Otto Environmental Foundation, Michael Succow Foundation, German Wildlife Foundation, the foundations within the German Stifterverband) or the national offices for nature conservation and environmental protection. In addition, references to restoration projects can be found in the municipalities or on their websites. A problem for restoration ecology, especially with regard to the critical analysis of the manifold practical experiences and their evaluation for future restoration projects, is that information is often difficult to find in the grey literature. In contrast to restoration projects that are successful, at least in the short term, there is often insufficient or no reporting at all on the failures, which makes it difficult to learn from them and to consistently further develop and adapt the approaches, methods, and measures of ecosystem restoration.

Courses or modules on restoration ecology or ecosystem restoration are meanwhile offered at Bachelor's or Master's level at many universities in Europe as part of the degree courses in biology, ecology, landscape ecology, environmental and resource management, environmental and ecological engineering, agricultural and forest sciences, landscape planning, etc. Study programs that focus exclusively on ecosystem restoration, possibly with a special focus (e.g., on wetlands), have been comparatively rare in Europe to date (◘ Table 1.2). In contrast,

◘ **Table 1.2** Examples of study programmes (Master's programme (MSc) or further education) with a focus on ecosystem restoration and restoration ecology in Europe (state: 2019)

Study program	University	Country	Type of Higher Education
Biology – Biodiversity: Conservation and Restoration	Antwerp	BEL	MSc
Ecology, Environmental Management, and Restoration	Barcelona	E	MSc
Environmental Diagnosis and Management	London (Royal Holloway)	UK	MSc
Environmental Protection: Restoration and Management of Environment	Warsaw	PL	MSc
Land Reclamation and Restoration	Cranfield	UK	MSc
Landscape Restoration for Sustainable Development: a Business Approach	Rotterdam (School of Management)	NL	Further education
Wetland science and Conservation	Bangor	UK	MSc

BEL Belgium, *E* Spain, *NL* Netherlands, *PL* Poland, *UK* United Kingdom ecosystem restoration and restoration ecology can be studied at universities outside Europe e.g., at the Simon Fraser University in Burnaby in Canada as well as at the Defiance College and Paul Smith's College, the Montana State University, the State University of New York, the University of Texas, and the University of Florida in the United States of America (SER 2017).

1.2 Ecological Terms and Key Concepts as a Basis for Ecosystem Restoration

Restoration ecology, as a sub-discipline of ecology is based on its scientific terminology and key concepts. Many of these key concepts are applied in practical ecosystem restoration (◘ Table 1.4). In many cases, ecological hypotheses are verified or falsified in a *trial-and-error* process in the context of restoration projects. Bradshaw (1987, p. 23) has aptly expressed this in the words "ecosystem restoration is an acid test for ecology". Even if, in the case of the need for immediate action (e.g., against the invasion of undesirable species) or novel habitat conditions (e.g., on abandoned industrial sites) and thus a lack of thorough scientific research, ecosystem restoration is more of an "art" than science according to van Diggelen et al. (2001, p. 115), restoration ecology, nevertheless, has achieved a comprehensive knowledge level in recent decades that can be profitably incorporated into restoration practice.

In the following chapters, some important ecological terms and key concepts are briefly outlined. Thereby, it is distinguishing between the population and species level and the ecosystem and landscape level, although this is not always consistently possible. For further study, please refer to the numerous ecological textbooks available (e.g., Chapman and Reiss 1999; Odum and Barrett 2004; Begon et al. 2005; Schulze et al. 2005; Smith and Smith 2009; Loreau 2010; Chapin III et al. 2011; Nentwig et al. 2012; Frey and Lösch 2014; Leuschner and Ellenberg 2017a, b) and the relevant chapters of this book, where specific reference to ecosystem restoration is made (Part II).

1.2.1 Species and Populations

▪ Species Pool

The number of species in a given spatial landscape section (e.g., a forest ecosystem) is determined by the available species at the next higher spatial level (e.g., forest landscape, biogeographic region) (Zobel 1997; Zobel et al. 1998; Herben 2000; Lepš 2001; ◘ Fig. 1.5). The species pool of a geographical area is not static, but dynamic. Today, this dynamic is mainly influenced by humans, i.e., species can disappear from the species pool due to the influence of land use and habitat changes (for the global situation, see IUCN 2016), or the anthropogenic introduction of non-native (non-indigenous, alien, exotic) species (*neobiota*; Kowarik 2010) increases the species pool, such as in cities (► Chaps. 5 and 19). The re-introduction of species can change both the local (e.g., re-introduction of grassland species to a meadow) and the regional species pool (e.g., re-introduction of megaherbivores or large predators) (► Chap. 4).

▪ Metapopulation

According to the metapopulation model, populations of a species are spatially separated as sub-populations within their range (Hanski and Gaggiotti 2004). In this system of populations, the extinction of a local sub-population and its re-establishment through immigration results in a constant change in the spatial distribution of a species within the potential settlement area (Nentwig et al. 2012). The exchange of individuals (gene flow) in this system of populations also helps to ensure that sub-populations do not become genetically impoverished. Different models assume sub-populations of different