Chapter 1

Long-Term Ecosystem Research Between Theory and Application – An Introduction

Felix Müller, Cornelia Baessler, Mark Frenzel, Stefan Klotz, and Hendrik Schubert

Ecosystems are dynamic entities. Triggered by external and internal factors, ecosystems change on a multitude of spatial and temporal scales. Nevertheless, in the past, the analysis of ecosystem dynamics has had top priority with reference to short time spans. The exploration of ecological interrelations usually has been carried out within a time period of three years, due to the typical funding and qualification duration of environmental research projects. As a consequence, to a great extent, the impacts of changes in the long-term have been neglected. This tendency has provoked a lack of information and methodological know how in this area. That strategy of course is not consistent with the long-term, precautionary way of thinking and acting expressed in political manifestations like the 2010 biodiversity target of the CBD or the EU Habitats Directive, which is an essential component of the sustainability principle. Additionally, real life has demonstrated the general significance of long-term processes: global climate change with its multiple consequences has fostered the awareness that there is an essential lack of scientific knowledge to build the ground for answers to the urgent long-term problems of mankind and the biosphere per se arising from these issues.

Many environmental impacts, like the widespread forest damages, the consequences of anthropogenic eutrophication and pollution, and the potential effects of genetic engineering, have been enfolding with slow change rates. Therefore reference values collected over a long period have become indispensable for sound analyses, predictions, and well-elaborated decision-making processes. Furthermore, the rising global trade does not only provoke long-term land use modifications, but leads to local ecosystems being increasingly burdened by the import of new plants and animals (Neobiota). Long-term observations are essential for evaluating the consequences of these changes. Additionally, long-term investigations are urgently needed to answer basic theoretical questions of ecology, e.g. to register the combined action of processes on different scales, to reduce the uncertainties concerning the irreversibility of structural ecosystem change, the orientation of successions, the success of restoration measures, to evaluate and improve the efficiency of protection measures, and to derive clear definitions of emergent ecosystem properties like resilience, stability, and adaptability. Moreover, these investigations are valuable even in terms of a concrete economic background, as the change in ecosystems often affects ecosystem services like pollination, food provision, or water purification.

This respective *need for research on long-term ecological processes* has been noticed by several scientists who have become active in the worldwide Long-Term Ecological Research Network. Also political institutions like the United Nations Convention on Biological Diversity, UNCBD, and the United Nations Framework Convention on Climate Change, UNFCCC, have formulated suggestions to ascertain long-term ecological research and long-term observations. Moreover, the Ecosystem Approach of the CBD (Principle 8, CoP V, UNEP, 2000, see http://www.cbd.int/decisions/?dec=V/6) claims that ecosystem management has to take long-term processes into consideration. Furthermore, the temporal

F. Müller (✉)
Ecology Centre, University of Kiel, Olshausenstraße 75,
D-24118 Kiel, Germany
e-mail: fmueller@ecology.uni-kiel.de

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Table 1.1 Exemplary targets of long-term ecosystem research initiatives (from the LTER-D web page – http://www.lter-d.ufz.de/)

Focal targets of LTER-D:

- To investigate complex ecosystem long-term processes under conditions of global change;
- To improve systems analysis methods, scale distinctions, and comprehensions of systems dynamics by integrating research on long-term and short dynamics;
- To enhance the cooperation between theory, empirics, and applications;
- To conceive early warning systems on the base of retrospective investigations;
- To elaborate scientific fundamentals for sustainable ecosystem management strategies;
- To enhance the knowledge about the effects of long-term processes by comparative analyses between research sites;
- To improve the collaboration between natural scientists and social scientists to better understand the dynamics of human–environmental systems;
- To integrate long-term environmental research and environmental monitoring;
- To support these objectives by joint data management structures, information exchange, and international cooperation.

goals of current environmental protection programs (for example: the EU Water Framework Directive or the Fauna-Flora-Habitat-Directive, Natura 2000) and the spans of climate scenarios are calculated for long-term time periods of 20 years and more. The implementation of suitable sustainable management strategies that argue in generations, as well as the interpretation of long-term scenario analyses requires a comprehensive and sound scientific basis which can only be derived from observations carried out during adequate time periods.

In addition to these time-related factors, the UNCBD's (CoP V, 2000) Ecosystem Approach essentially aims to preserve *ecosystem structures and functions* in order to ensure their long-term social, ecological, and economic benefits (ecosystem services). The seventh principle of Agenda 21 points in the same direction: *health and integrity of ecosystems* have to be preserved, protected, and, if necessary, re-established. A third aspect of relevant international arrangements calls for a continuing *integration of socio-economic approaches* in environmental management. The combination of socio-economics and ecosystem analysis is the basis for the realization of these holistic concepts, which should be used for both the ecosystem research and the development of principles for advanced decision making.

The application of these three basic principles (long-term investigations, ecosystem approaches, linkages between human and environmental systems) and the development of appropriate actions require specific investigations of long-term ecological development in which ecological and socio-economical aspects are combined by an interdisciplinary long-term ecosystem approach. These are basic motivations of several national and international research networks, which are cooperating within the ILTER programme (International Long-Term Ecosystem Research). To illustrate the targets of these groups, Table 1.1 demonstrates some basic objectives of the German LTER group.

The typical timescales of long-term investigations are demonstrated in Fig. 1.1. In this context, it has to be noted that the time span between a year and a century should be understood as an eligible expansion of the traditional research periods. To understand ecosystems, of course the integration of scales has to be put into the focus. Long-term processes and short-term dynamics are interlinked, and potentially the analysis of the respective temporal networks will provide new emergent properties, which arise due to the overall connectivity. Therefore the theory-based *integration* of scales is much more important than the distinction of spatio-temporal units.

Taking the described necessities as a basic requirement, the prime objective of this book is to focus on studies dealing with the investigation of complex, long-term ecological processes with regard to global change, the development of early warning systems, and the acquisition of a scientific basis for strategic conservation management and for the sustainable use of ecosystems. The central motivation of this book is to stimulate the international discussion to foster the cooperation within the worldwide ILTER organization. Additionally this book shall demonstrate the high significance of long-term-oriented research questions for the understanding of ecosystems, as well as a better application of scientific methodology in environmental practice. Following these targets, the book is structured into eight sections, each of them posing

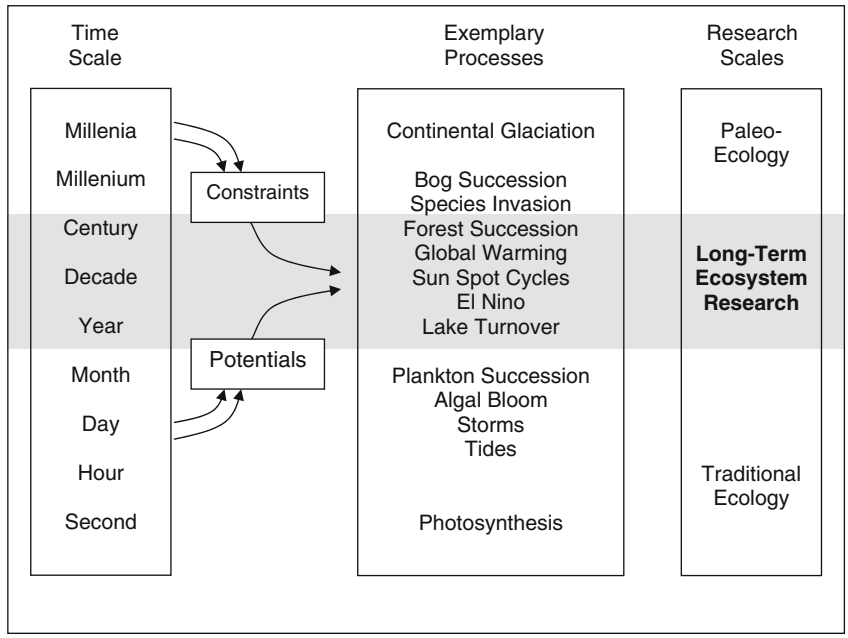

Fig. 1.1 Assigning different timescales to exemplary ecological processes and typical research scales, after Hobbie, Carpenter, Grimm, Gosz, and Seastedt (2003)

distinct questions (Fig. 1.2). The basic outline of this structure will be sketched in the following part of this Introduction.

Part II: The significance of ecological long-term processes: The focal questions of this first part of the book are the following: *Which are the most important processes calling for long-term-research? Which questions arise from these objects? and Why is it necessary to investigate their interrelationships?* To find arguments for a thorough discussion of these questions, Müller et al. discuss these items from the viewpoints of ecosystem theory, trying to list and describe recent theoretical problems which need long-term observations to be better understood or even solved. Besides the respective discussion of research demands that originate in theoretical considerations,

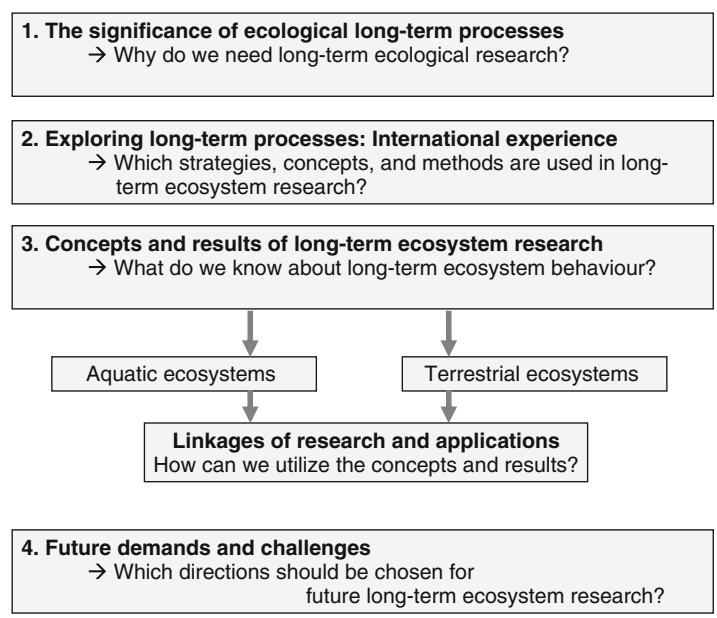

Fig. 1.2 Basic structure of the book

the potentials of modelling, data management, and statistics are demonstrated. One of the actual theoretical fields mentioned in the introductory chapter is described in more detail in the second chapter: Fath and Müller analyse environmental change as an explication of self-organized trajectories. Some basic ideas about ecosystem growth and development are reviewed, and the classical succession approach is linked with actual concepts of collapse, break down, and decay. While these two chapters are highlighting the necessity of long-term ecosystem research from aspects of systems theory and thermodynamics, Schimming et al. are illuminating long-term research conceptions in relation to environmental monitoring activities. Of course both branches of environmental analysis can mutually profit from each other: Scientists can be enthusiastic interpreters of monitoring data to better solve their long-term problems, and on the other hand, these solutions can be extremely valuable for any application in environmental management. As long-term management concepts should be developed although they are actually available only in a small portion, this symbiosis should be enhanced in the future.

Part III: Exploring long-term processes – International experience: The chapters of this section are dealing with the following questions: *How are LTER programmes developing? Which are their typical concepts, results, and research questions? Which experience has been made in the utilization of specific long-term related methodologies?* These questions are discussed from different viewpoints: Initially Gosz et al. report about 28 years of the US-LTER Program. The authors demonstrate the goals of their exemplary initiative, its history, motivations, and outcomes, the organizational structure, and the challenges which US-LTER scientists will be facing in the future. In many points those research demands are also realized by ecologists in Europe as demonstrated in the chapter of Mirtl.

In the two subsequent theoretical chapters, the potentials of ecosystem modelling are described by Gnauck et al. which concentrate on the powerful tools of statistics and their applications in long-term ecology. Hostert et al. additionally show the role of remote sensing techniques and their contributions for the mission of LTER, illustrating theoretical approaches as well as examples from the US LTER Programme. Of course, besides remote sensing, many basic methodologies are applied in long-term ecosystem research. Several examples can be found in the next section.

Part IV: Concepts and results: Presenting and interpreting long-term ecological processes: In this section, the following questions are discussed: *Which are the basic results of existing long-term research projects? Which processes have been observed in different ecosystem and landscape types? Which are the main results of these investigations? How can those results be used to link research and application?*

In this part (IV) case studies from *different aquatic ecosystem research* projects are presented. Starting with interesting experience from several coastal time series van Beusekom et al. demonstrate recent changes in the ecological structures and functions of the Wadden Sea ecosystems in Northern Germany. Their main questions are related to the consequences of temperature, salinity, and nutrient changes, the consequences for plankton and benthos communities, and the influence of alien species, which can be observed very realistic in the Wadden Sea. Stockmann et al. are expanding the aquatic research area, searching for externally forced signals in biological time series in the overall North Sea. The authors are using extensive simulations of varying external physical factors to explain the trends and shifts of biological parameters. A third type of aquatic ecosystems is described in the chapter of Schubert et al.: Based on several long-term data sets, typical developmental tendencies in brackish ecosystems are reported, including gradient-related comparisons of the Baltic Sea, coastal lagoons at the Baltic and Chesapeake Bay. The authors underline the necessity and the added value of long-term investigations to better understand these highly variable systems. Finally long-term developments in two freshwater ecosystem types are described: On the one hand, Köhler shows recent drivers, pressures, and impacts on lake ecosystems, taking into account the consequences of eutrophication, acidification, species invasions, and climate change, stressing the potentials and limitations of long-term research concepts. On the other hand, Poschlod et al. present the results of long-term monitoring investigations in rivers of South Germany since the 1970s. The authors are using macrophytes as focal indicators for the assessment of water quality.

Part V refers to the results of *terrestrial ecosystem research* investigations. Also in this part of the

book, several different ecosystem types are illuminated, and different ecosystem components are analysed. Focussing, i.e. on soil mesofauna, Koehler and Melecis provide a methodological framework for respective faunistic, ecosystem-based analyses and show results from Collembola and Gamasina dynamics in different study sites. Highlighting the ecosystem water balance, Lischeid et al. show the results of tracing biogeochemical processes in small catchments using non-linear statistical methods. Schindler et al. concentrate on long-term measurements to quantify the impact of arable management practices on deep seepage and nitrate leaching in agricultural ecosystems. In the following chapter, the focus is changed to long-term processes in forest ecosystems: Tavares et al. are demonstrating the flux-based results of long-term ecosystem research in a beech forest in Northern Germany, concentrating on the flows and storages of elements through the compartments of the investigated beech forest ecosystem. Subsequently, Syrbe et al. provide a report about concepts, methods, and results of monitoring landscape change. They create a methodological framework, which is exemplified, i.e. with reference to hypothesis testing. Baessler et al. demonstrate the relative importance of historical to recent landscape structure and environmental conditions on plant species diversity and genetic variation. They demonstrate the importance of long-term studies to understand ecological processes and to consider this knowledge in the future. Finally Schmidt et al. develop a system for the integration of long-term environmental data by the example of the UNECE heavy metals in mosses survey in Germany. The authors are using a WebGIS-based metadata system, which is well suited for applications in LTER systems.

Part VI the *linkages between research and applications* are focal items of four chapters: While Luthardt refers to her experience with monitoring ecosystems in Biosphere Reserves, Heurich et al. show the potential of National Parks to be used as model regions for interdisciplinary long-term ecological research. The authors demonstrate the added value of long-term investigations for actual problems of environmental management in an exciting environment, and they demonstrate potentials for long-term collaboration between different nations. In contrast to Heurich's mountains of the Bavarian Forest, Diederichs refers to the experience of National Park management in the Wadden Sea of Schleswig-Holstein, describing how to turn long-term monitoring into policy. In the fourth chapter of this section, the conceptual framework and the design of ecological monitoring networks are described by Jones et al. from two sides: On the one hand, the design of the US NEON network is considered at the intersection point between research and application, and on the other hand, the new research network TERENO is described, which is planned to investigate ecosystem processes with a long-term conception. All of these chapters convincingly demonstrate the demands for long-term knowledge in theory and practice, and they illustrate the high potential of linking research and management.

Part VII: Future demands and challenges: The chapters of this section try to find answers to the following queries: *Which are the future steps of long-term ecological research? Which challenges have to be solved in the forthcoming years? How can we better integrate different research directions?* In this context, Singh et al. present a conceptualisation and a theoretical basis for long-term socio-ecological research (LTSER), trying to integrate the socio-economic dimension into long-term ecological research. The authors also provide some results and modelling studies from Austrian pilot test areas. Ohl and Swinton are concentrating on the linkages of environmental and societal dynamics, also proposing a future network of integrated human–environmental research sites. Thereafter Dilly et al. demonstrate the value of long-term research with reference to ecosystem manipulation and restoration on the basis of long-term conceptions. Here long-term approaches are used not only to control the success of restoration measures but also to develop intelligent directions of restoration. Following, Fischer et al. present a new integrated project in Germany, the exploratories for large-scale and long-term functional biodiversity research. Finally, there are some summarizing *conclusions (Part VIII)* of the book, concentrating on future long-term-related research questions and challenges.

References

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