Chapter 5
Sustainability and Ecosystems

**Henrik von Wehrden, Goddert von Oheimb, David J. Abson,
and Werner Härdtle**

Abstract Maintenance of human well-being is highly dependent on nature. The natural environment provides a source of both directly used goods and services that support human livelihoods and an intrinsic value that contributes to human flourishing. Today, much of the planet is influenced or even transformed by human activity, and natural ecosystems are increasingly under threat. Ecology and conservation biology are crucial for understanding and quantifying changes in ecological systems. Moreover, ecology in conjunction with other branches of science provides key insights to enable management options for supporting a sustainable future for our planet. Here, we give an overview of the relationship between biodiversity, ecosystems, and sustainability. First, we introduce the notion of biodiversity, then we present the links between biodiversity, ecosystem functions, and services, in which ecosystem services are the benefits people derive from ecosystems. Finally, we outline the current threats to ecological integrity and provide a brief overview of the links between ecology and other disciplines within sustainability science.

Keywords Biodiversity • Ecosystem function • Ecosystem services

H. von Wehrden (✉)
Centre for Methods, Leuphana University, Lüneburg, Germany

Institute of Ecology, Faculty of Sustainability, Leuphana University, Lüneburg, Germany

FuturES, Leuphana University, Scharnhorststr. 1, 21335 Lüneburg, Germany
e-mail: henrik.von_wehrden@leuphana.de

G. von Oheimb
Institute of General Ecology and Environmental Protection, Technische Universität Dresden, Tharandt, Germany

D.J. Abson
Faculty of Sustainability, Leuphana University, Lüneburg, Germany

FuturES, Leuphana University, Scharnhorststr. 1, 21335 Lüneburg, Germany

W. Härdtle
Institute of Ecology, Faculty of Sustainability, Leuphana University, Scharnhorststr. 1, 21335 Lüneburg, Germany

1 Introduction

The notion of sustainability is a largely anthropocentric concept (regarding the world in terms of human values and experiences) concerned with sustaining human well-being (Richardson 1997). However, the maintenance of human well-being is highly dependent on nature. The natural environment, here conceptualized via the concept of biodiversity, is a source of both directly used goods and services that support human livelihoods and an intrinsic value that contributes to human flourishing (Randall 1991). Today, much of the planet is influenced or even transformed by human activity, and natural ecosystems are increasingly under threat (Rockström et al. 2009). Ecology and conservation biology are crucial for understanding and quantifying changes in ecological systems. Moreover, ecology in conjunction with other branches of science provides key insights to enable management options for supporting a sustainable future for our planet (Cardinale et al. 2012). This chapter gives an overview of the relationship between biodiversity, ecosystems, and sustainability. First, we introduce the notion of biodiversity, then we present the links between biodiversity, ecosystem functions, and services, in which ecosystem services are the benefits people derive from ecosystems. Finally, we outline the current threats to ecological integrity and provide a brief overview of the links between ecology and other disciplines within sustainability science.

2 Biodiversity

Biodiversity (the contraction of "biological diversity") is a term used to describe the totality and variety of life on Earth. Formally, the Convention on Biological Diversity defines biodiversity as "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" (http://www.cbd.int). This view is now generally accepted, and we can consider three levels of biodiversity: genetic diversity, species diversity, and ecosystem diversity.

Genetic diversity is the heritable variation within and between populations of organisms. It finds its expression in both externally visible features (e.g., the color of a dog's fur) and at the level of molecules (e.g., the blood groups of humans). Ultimately, genetic diversity is based on the variation in the sequence of the four base pairs which, as components of nucleic acids, constitute the genetic code. For the survival of species, genetic diversity is of major importance, since it allows species to adapt to environmental change. From a human perspective, the enormous variability of numerous cultivated plants and domestic animals is a crucial aspect of biodiversity, both in terms of species diversity and regarding the genetic diversity of these species. For example, more than 35 mammalian and bird species have been domesticated for use in agriculture and food production, and there are more than

8,000 recognized breeds. Similarly, rice originates from one species, while the International Rice Database holds records of about 100,000 rice cultivars. The genetic diversity in a given species provides the basis for adaptations to future environmental changes, and maintaining genetic diversity of on-farm plants and animals is, thus, a key issue in sustaining agricultural production (e.g., Zhu et al. 2000; Tilman et al. 2006).

Species richness, that is, the number of species in a given area, represents the most commonly used metric for characterizing the diversity of life. Species diversity is an abundantly used measure of biodiversity within the scientific literature, so much so that it is often used as a synonym for biodiversity. This is because species are well-known and distinct units of diversity, and they are often relatively easy to identify in the field. Worldwide, about 1.8 million species have been described to date, and estimates for the total number of species existing on Earth range from 5 to 30 million (Millennium Ecosystem Assessment 2005). In terms of species numbers alone, much of the biodiversity on Earth appears to consist essentially of insects and microorganisms.

Ecosystem diversity is the diversity of ecosystems (i.e., the embedding of species or communities interacting with the non-biotic components of the environment), natural communities, and habitats in a given place. Because an ecosystem is a community of organisms and their physical environmental interactions, ecosystem diversity is, in essence, the variety of ways that species interact with each other and their environment. While there are many well-defined measures of genetic and species diversity, it is difficult to assess ecosystem diversity precisely due to the complexity of the interactions and the lack of sharp boundaries between ecosystems. It has to be kept in mind, however, that in order to fully capture biodiversity, it has to be integrated with other metrics.

Biodiversity is not evenly distributed across the Earth (Kleidon and Mooney 2000). For many taxonomic groups, there is a latitudinal gradient in species richness, with high numbers of species occurring in the tropics. Moving from the low to high latitudes, the species richness decreases. Determining why these gradients occur has long been a core issue in ecological research (Gaston 2000). A few environmental variables can explain a substantial proportion of variation in the spatial patterns of biodiversity, such as temperature, water availability, net primary productivity (i.e., the amount of biomass produced in a given area), or evapotranspiration (i.e., the sum of evaporation and plant transpiration from the land surface to the atmosphere). There is, however, no pattern without variations and exceptions, and we are far from a universal theory or model for predicting the spatial distribution of biodiversity. Nevertheless, it is possible to locate the areas that are the most immediately important for conserving biodiversity. These so-called biodiversity hotspots hold especially high numbers of endemic species, i.e., species that are prevalent in, or peculiar to, a specific locality (Myers et al. 2000). In very recent scientific studies, priority areas worldwide have been mapped out that suggest schemes for protecting vulnerable species and focusing conservation efforts (Jenkins et al. 2013; Le Saout et al. 2013).

More information on biodiversity can be found in Gaston and Spicer (2009).

- *Questions*
    1. *How is biodiversity defined?*
    2. *Which group of species has the highest number of species?*
    3. *What drives the distribution of biodiversity and individual species, and what limits it?*

3   Ecosystem Functioning and Services

The different biotic (living) abiotic (non-living physical and chemical elements) components of the ecosystems found on the planet show strong interactions and relations, which taken together are coined as "ecosystem processes" (Daily 1997). For instance, carbon fluxes, pollination networks, and herbivory rates are all examples of ecosystem processes, and the joined effects of all these different processes are usually referred to as "ecosystem functioning." Biodiversity is often positively related to ecosystem functioning, in which higher rates of biodiversity are linked to higher rates of ecosystem functioning (Cardinale et al. 2006). Due to the alarming rates at which biodiversity is decreasing and ecosystems are being degraded on a global scale (see below), considerable research efforts in ecology have investigated the biodiversity-ecosystem function linkages. Many experimental approaches focusing on the relation between biodiversity and ecosystem functioning have been established within the last decades in different environmental settings (e.g., Tilman et al. 2006). Controlled environments were created through manipulation of ecosystems, enabling the study of important ecosystem processes and their relationships to biodiversity. Experimental designs frequently involve a manipulation of the variance of different species combinations within given levels of biodiversity. These different species combinations are suggested to account for the variance found within real ecosystems.

Specific species are grouped in relation to specific ecosystem processes based on their key characteristics, which are called traits; several databases and large research projects are currently generating coherent standards on these species' information and characteristics, thereby reducing pattern complexity within ecosystem functioning research while often increasing the explanatory power of ecological models. In addition, phylogenetic databases are increasingly gaining importance in ecological research (Winter et al. 2013). Phylogenetics defines the systematic position of a species (e.g., its family or genus) into the wider systematic background and quantifies the relationships between different species (see below).

In order to understand the complexity and interrelations within ecosystems and their relations to human well-being, the concept of ecosystem services has gained momentum in the last couple of decades (Seppelt et al. 2011). The concept of ecosystem services attempts to model directly or indirectly appropriated ecosystem structures, functions, or processes that contribute to human well-being (Millennium Ecosystem Assessment 2005). The Millennium Ecosystem Services Assessment

was the first large collaborative approach to generating pivotal knowledge on eco-system services on a planetary scale (see Box 5.1). Several national and regional studies and assessments investigating the complexity of ecosystem services dynamics have followed since, and an increasing number of studies derive system knowledge on local scales. Ecosystem services are strongly related to biodiversity through complex indirect relations between ecological functions and human well-being.

The ecosystem services approach is rooted in the attempt to understand the main sources of human well-being in complex dynamic socio-ecological systems (Daily 1997). Defining the boundary of one system is often the first challenge, since the borders of most systems are not discrete, but instead show linkages and interactions across different scales and system components (Post et al. 2007). Land use within human-dominated landscapes is of primary importance in the context of understanding ecosystem services, since many ecosystem services are specifically linked to one or several land-use types, e.g., carbon sequestration (Foley et al. 2005). The variability in ecosystems service provision across space is driven by two key factors. Categorical phenomena such as land use (e.g., forests and agricultural land) drive broad scale dynamics of ecosystem services provision. However, within a given ecosystem, gradual changes in ecological structures can also alter the provisioning of ecosystem services. For example, primary productivity changes along climatic

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Box 5.1: The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) was a groundbreaking, global interdisciplinary scientific endeavor undertaken between 2001 and 2005 and involved the collaboration of more than 1,360 experts worldwide, carried out under the auspices of the United Nations. The MA assessed the consequences of ecosystem change for human well-being and developed scenarios to consider how ecosystems and the provision of ecosystem services may change in the future. The MA produced five main reports (A Framework for Assessment, Current States & Trends, Scenarios, Policy Responses, and Multiscale Assessments), as well as a number of shorter synthesis reports (http://www.millenniumassessment.org). The main finding of the MA was that over the past 50 years, humans have rapidly, and often irreversibly, changed ecosystems, largely to meet rapidly growing demands for food, freshwater, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.

The MA findings provide a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably. The MA was crucial in the development of other major scientific endeavors related to ecosystem services, such as The Economics of Ecosystems and Biodiversity (www.teebweb.org/) and the recently set up Intergovernmental Panel on Biodiversity and Ecosystem Services (www.ipbes.net).

gradients, which, in turn, affects the amount of food (provisioning ecosystem services) that can be provided within a particular system.

Besides being able to generate descriptive knowledge (functional relationships between ecosystem functions and human well-being) about a specific system, normative evaluations (judgments of how the world should be) are a key component in understanding the value that humans ascribe to ecosystem services. While monetary values are often ascribed to ecosystems services, normative evaluations can go beyond economic realms and consider non-monetary values that humans ascribe to ecosystems. For example, sense of place, cultural identity, and the intrinsic value of nature are recognized ecosystem services that cannot easily be quantified in terms of monetary values. The ecosystem services approach is increasingly recognized and applied in policy and conservation planning and research. A global institution was recently found to foster and link biodiversity and ecosystem services research and its implementation with stakeholders (www.ipbes.org).

Current ecology and conservation approaches are working both bottom-up and top-down. While the ecosystem functioning research investigates fundamental relationships between parts of the ecosystem on a local scale (bottom-up), the ecosystem service concept usually focuses on a wider scale (which can be top-down) relating generalized ecosystem functions to human well-being. However, a holistic understanding of ecosystem services needs to acknowledge local-regional complexity, i.e., combining bottom-up and top-down approaches.

- *Questions*

    1. *How are ecosystem services defined?(Give some examples.)*
    2. *How are values ascribed to ecosystem services?*
   3. *Does the concept demand a bottom-up or a top-down approach?*

4   Global Threats to Biodiversity and Ecosystem Functioning

Human activities have altered the world's biodiversity, the functioning of ecosystems, and related ecosystem services in multiple ways. Global biodiversity currently changes at an unprecedented rate, and there is evidence that biodiversity losses are strongly linked to both important ecosystem processes and society's use of natural resources (Sala et al. 2000).

Despite the multiples ways in which humans have affected and will affect the functioning of ecosystems in the course of this century, recent research has identified five drivers of global change that are considered the most important regarding their impact on biodiversity loss and shifts in ecosystem functions. Ranked according to their projected impact on (terrestrial) biodiversity loss, these drivers are "land-use changes," followed by "climate change," "nitrogen deposition," "biotic exchange," and elevated levels of "atmospheric carbon dioxide" (Fig. 5.1, Sala et al. 2000).

Land-use change: This driver is expected to have the largest global impact on biodiversity by the year 2100, mostly because of its devastating effects on habitat

Fig. 5.1 Relative effects of major drivers of changes on biodiversity. *Thin bars* are standard errors and represent the variability among the different biomes analyzed (from Sala et al. 2000)
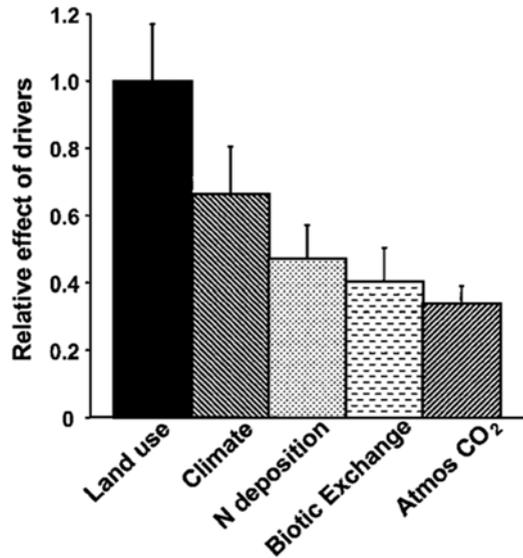
availability and related species extinctions. Land-use changes have affected tropical rain forests in particular, which are currently subject to extensive clear-cutting due to non-sustainable harvest of timber and their conversion to arable land or crop plantations. Since tropical rain forests host a huge proportion of the earth's biodiversity, they are considered the most important "biodiversity hotspots" worldwide (Myers et al. 2000).

Climate change: Climate change will be the second most important driver of biodiversity loss, mostly as a result of the expected warming at higher latitudes (but also at higher elevations, e.g., in the Alps). Recent analyses suggest that 15–37 % of a sample of 1,103 land plants and animals would eventually become extinct as a result of climate changes expected by 2050 (Ball 2012).

Nitrogen deposition: Anthropogenic nitrogen emissions (resulting from fuel combustion and agricultural activities) have tripled since the beginning of industrialization in the nineteenth century. As the productivity of plants in most ecosystems is limited by nitrogen, increasing nitrogen availability not only impacts plant productivity but strongly affects the competition between plant species (so-called interspecific competition) in different environments. As a consequence, many weak competitors that are unable to use an increasing nitrogen supply to enhance their biomass productivity have gone extinct in nitrogen fertilized environments. Nitrogen deposition will affect biodiversity hotspots during the course of this century due to increasing use of artificial fertilizers in previously low-input agricultural systems.

Biotic exchange: Biotic exchange describes the shift in the species composition and species assemblages in a particular area due to the encroachment of neobiota (non-native species introduced by humans). Depending on their competitiveness, introduced species with an aggressive spreading behavior are often classified as "invasive species" or "invaders." Introduced species are considered a particular

problem in the tropics and subtropics, where neobiota often finds ideal conditions for growth and reproduction (in contrast to the temperate and boreal zone, where strong winters often limit or prevent the establishment of neobiota).

Atmospheric carbon dioxide: Increasing levels of atmospheric carbon dioxide (attributable to the combustion of fossil fuels) affect one of the most important biochemical processes typical of primary producers, photosynthesis. Since plants have different mechanisms in fixing atmospheric carbon dioxide, increasing levels will affect the interspecific competition of species characterized by a respective fixation mechanism. This will provide a competitive disadvantage for some species, which in turn may cause their extinction in the long term.

Despite an increasing knowledge of ecosystem responses to global change, our ability to anticipate global change impacts on ecosystem functions and services is still very limited (Loreau et al. 2001). Moreover, it is very likely that global change drivers will interact in a non-additive way, which in turn might cause antagonistic (canceling or damping) or synergistic (amplifying) effects on ecosystem responses. However, anticipating these responses to co-occurring global change drivers (such as climate change and increasing nitrogen deposition) will be crucial in the guidance of management, policy, and conservation efforts aimed at long-term mitigation of global change effects (Zavaleta et al. 2003).

- *Questions*

    1. *What are the major threats to biodiversity?*
    2. *Is climate change a threat to biodiversity today?*
    3. *How can we mitigate the effects of global change?*

5 Developing Solutions to These Threats: Interdisciplinary and Transdisciplinary Efforts

Tackling the challenges our planet is facing regarding global environmental change calls for a fundamental change in societal and individual human behavior (Fischer et al. 2012). Many of these challenges, such as depletion of ecosystem services, loss of biodiversity, and changes in environmental entities and characteristics, have been primarily investigated by natural sciences. The natural sciences generate baseline information to identify critical changes to the environment, which in turn often lead to discussions both from policy-makers and civil society. Ecological research and conservation biology are therefore of primary importance for achieving a sustainable future and harmonizing people and nature, especially but not exclusively if they aid normative and transformative knowledge creation (e.g., for ecosystem services, see Abson et al. 2014). Many discussions that found their way into the broad societal discussion started as basic research, including climate change, waldsterben (forest loss due to acid rain), and ocean acidification. Basic natural science research contributes to many applied aspects of environmental problems that link other

disciplines to sustainability. Topics rooted in ecology and conservation can help identify socio-ecological complexity and link to numerous other aspects of sustainability. However, ecology alone cannot tackle sustainability problems that are inherently linked to both natural and social systems.

The social sciences, stakeholder involvement, and mutual learning (both across scientific disciplines and, more broadly, in society) help to identify key drivers of ecosystem services and biodiversity loss. Many topics in ecology and conservation demand an exchange of knowledge about socio-ecological systems, such as governance and behavioral change, which are generated in other scientific disciplines. Consequently, socio-ecological research must link fundamental knowledge and system understanding between different disciplines and calls for strong interdisciplinary connections and exchange, including solution-orientated research. Ideally, this transdisciplinary process (engaging multiple scientific disciplines and the wider society) creates a transformative process based on scientific evidence that links back to, and helps change, societal dynamics and processes toward more sustainable human-environmental interactions.

- *Questions*

    1. *How is ecological research linked to policymaking?*
    2. *How can ecological research benefit from stakeholder involvement?*

Further Reading

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