Environmental Challenges and Solutions

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Carsten Hobohm *Editor*

Perspectives for Biodiversity and Ecosystems

Springer

Environmental Challenges and Solutions

Series Editor

Robert J. Cabin, Brevard College, Brevard, NC, USA

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Perspectives for Biodiversity and Ecosystems

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Preface

The conservation of biodiversity and ecosystems is by its very nature a task which cuts across many disciplines.

Biodiversity—the diversity of life—and *ecosystems*—spatial units of living organisms in their physical environment—as a topic belong to the natural sciences, and here in particular to biology, ecology, and biogeography.

Protecting ecosystems and biodiversity *conservation* involve the cultural use of nature. What is it permissible to do, what measures should we adopt, and what should we refrain from doing? Addressing these kinds of interdisciplinary questions typically requires addressing associated ethical, political, educational, legal, and economic issues.

Consequently, we believe that effective biodiversity and ecosystem conservation requires more collaboration between the natural sciences and other relevant disciplines such as the social sciences and humanities.

Conserving biodiversity and ecosystems is not only important for plants and animals but is also essential to the survival and well-being of humans and our culture.

This book deals with the perception, perspectives, and prediction of environmental processes seen within a framework of the nature of ecosystems and human cultures.

The global human population continues to grow and nobody currently knows if it will reach a maximum of 10 or 15 billion people. Furthermore, there are few examples of regional-scale sustainable actions that have planning horizons greater than a couple of decades. Thus, it is unknown whether humans will be able to handle the crowded planet in a sophisticated manner or whether they are more likely to act as hounded, stressed out, and murdering animals. In many cases, however, it will make sense to take worst-case scenarios into account.

Many authors argue that understanding and solving complex problems such as conserving biodiversity and ecosystems requires a holistic approach. However, a core problem with this approach is that it can only put forward overarching and generalized arguments and recommendations. This is because in this framework, all the threads within this widely spun web have to be taken equally into consideration.

The most far-reaching kind of consideration in radical physiocentric or holistic environmental ethics implies that everyone is thoughtful of everything. In this sense, even valuing living processes higher than abiotic ones would be reductionist, as abiotic and biotic processes interact with one another.

Consequently, in this book, while acknowledging the many connections and interdependencies among biodiversity, human beings, and human cultures, we analyze these components separately.

This is the only way to obtain a focused and unbiased view of specific individual environmental issues. Indeed, such a procedure is particularly called for when judging the impacts of human activity on nature because it would otherwise be impossible to make selective use of the specific indicators. An important principle in this process is the law of series and continuity. Predictions are often all the more realistic the more precisely they are able to track past trends and to project them into the future. Periods of drought and ensuing crop failures are more frequent in specific semi-arid regions of the world; in the oceanic and cool temperate regions, rainy summers can cause crop failures as well. Deserts and alpine regions are not affected because crops are not cultivated there; nor, for example, are many regions of the wet tropics. All the oceans of the world are affected by rising sea levels. Nevertheless, some coasts and islands are not affected at all—for geological reasons, as movements of the Earth's crust and sedimentation rates can overcompensate the rise in sea level. This global phenomenon, then, only becomes a true problem in certain parts of the world.

This can, however, mean that the social sciences, the natural sciences, and the media arrive at very different evaluations of the significance for humans and nature of certain environmental problems.

There is now a gratifying variety of writings on the history of the environment and the current anthropogenic impacts on the environment. Indicator systems have also been developed which take into account the risks and the well-being of people, qualitative and quantitative changes in ecosystems, the conservation of biodiversity, and the greater risk of extinction facing some animal and plant species. This all provides a sound basis for linking these various levels with one another.

This book broaches the issue of perspectives and prognoses for the impacts of anthropogenic activity on ecosystems and species conservation. Its goal is to improve assessments of the impacts of human activity on the environment.

More specifically, we investigate the following kinds of questions:

How can biodiversity and ecosystems be more effectively protected?

How can we ensure that planning and organization of nature protection measures are no longer regarded as backward-looking and conservative but as a cultural achievement and a progressive undertaking?

How can the greatest possible effect be achieved in the management of biodiversity but at the same time expenditure be kept low?

What indicators are suitable for monitoring the required actions and monitoring success?
How much influence do economic systems and cash flows have?
How important for flora and fauna are power relationships and economic liberalism?
What are the most effective and targeted means of tackling the particularly dubious legal and illegal evils of the traditional and the modern?
What impact does the sale of exotic and rare plants or animals have on the remaining wild populations in their native habitats?
How do the specific problems and management measures taken to deal with ecosystems and biodiversity differ in the various regions of the world?
Why is environmental education so important?
How can we avoid any further loss of a species?

The book is divided into four sections: past, present, future, and synthesis.

The first section discusses historical aspects and focuses on the natural and cultural connections between humans and nature in the past. The past includes the history of our abiotic environment, the evolution of the biota, and the history of human influences on ecosystems, but the constraints of the evolution of our psychological constitution and development of our cultures depending on natural resources as well.

Which events and case studies of the past can serve as positive or negative examples? The knowledge of the history of ecosystems and biodiversity under human's influence can help to understand recent challenges and planning of the future.

The second section deals with current processes and tendencies. The descriptions and explanations given there provide a basis for distinguishing between what is inevitable and what is optional. We highlight recent problems of influences on ecosystems and species conservation caused by human behavior, wishes, and money.

The third section is, by its very nature, speculative and thus entails uncertainty. Looking to the future we attempt to show, based on the current state of scientific knowledge, the optimal ecosystem conditions for the survival and evolution of biota despite anthropogenic influence or, rather, with human support. We aim to describe realistic options under worst-case scenarios—further growth of the world population, increasing demand on resources, and changing climate. We also describe what would have to be done to prevent species extinction and further damage to ecosystems.

The fourth and final synthesis section includes a meta-analysis from all the contributors to this book. The goal of this meta-analysis is, with a strong focus on human impacts on the environment and a work order, to analyze, enable, and manage the protection, survival, and evolution of all species on Earth.

We venture prognoses in this book and we will fail. However, we hope that we will be wrong on the right side.

Flensburg, Germany Carsten Hobohm

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I am thankful to the editor of the series *Environmental Challenges and Solutions*, Robert Cabin, and to the publishers of *Springer Nature*, notably Éva Loerinczi, who kindly opened the door for this book project and guided the process whenever it was necessary.

We invited many experts of various disciplines to write a chapter of this book. It is wonderful that many of them consented to take part. I am very happy that scientists of so different disciplines were able to find a collective goal and language—which is not usual. Therefore, I sincerely thank all coauthors and reviewers.

My university in Flensburg offered conditions of local warming, financial support, and a sabbatical semester. I am thankful to members of the chair and my department who enabled favorable socioecological conditions.

My interest in landscape ecology and environmental sciences particularly developed in two schools of Geobotany and Macroecology (universities in Freiburg and Hannover). Therefore, I am very thankful to the working groups, notably to Richard Pott, who was the supervisor of my doctoral studies and director of the Department of Geobotany at the University of Hannover.

Last but not least, I am thankful for the support by my wonderful family, to Uta, Merel, and Till.

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He edited a book on *Biodiversity* (2000, in German language) and *Endemism in Vascular Plants* (2014). He and his team are organizing, updating, and analyzing different databases, for example, on *Endemic Vascular Plants in Europe* (EvaplantE), *Plant Endemism Assessment of Red List habitats in Europe* (PEARL), and a database on *hyperendemics* (Hypedata).

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Part I
Basics, Legacy and Historical Purposes

What can we learn from our evolutionary and ecological history?

How is the environmental behaviour of humans guided by natural surroundings?

How important is our social and cultural behaviour for the understanding and management of ecosystems?

Are nature and culture antipodes or two sides of the same coin?

What can we learn from constraints of our psychological constitution?

How important are communication and education?

The species decline increased dramatically during the last centuries and decades. Will this development continue or are we able to invert the trend?

In this section we analyse what we can learn from the past for the management of the environment and the organization of nature conservation programmes for the future.

Environmental History

Carsten Hobohm

Abstract Landscapes and ecosystems are composed of biota, including humans and their abiotic environment, and reflect evolution, historical events, and ecological conditions. Not only does the physical environment control human culture and behaviour (*environmental determinism*) but social behaviour and perception also have natural and cultural roots, and influence the direction and success of processes, conditions and measures in the landscape.

Meanwhile, all ecosystems and many natural attributes of biodiversity are affected by human activities and chemical products. The terms *culture*, *landscape* and *environment* are linked with different relationships between the physical environment and human life. The short timeline presented here exemplifies natural conditions of culture and human influence on nature.

Global environmental history shows an increasing trend in the spectrum of resources used as well as in the intensity of resource use by humans. The human population is still growing, accompanied by hunger crises, death and migration.

These trends are still continuing today, even though one day they will inevitably reach a maximum or changeover point, and although many local and regional attempts in the past have already shown recycling, reduction, disclaimer, and cultural perspectives which show means of reversing the trend.

History to date does not show any globally effective package of measures to protect the atmosphere, hydrosphere, lithosphere, pedosphere or biosphere. Environmental programmes have regularly been more successful at local to national, and sometimes at supranational scales.

Issues of water quality, quantity, availability, drought, severe floods, tsunamis, the damage and reconstruction of ecosystems and diseases linked to the environment have been and will most likely continue to be the greatest environmental problems facing humans, and humans pose the greatest problem for biodiversity and ecosystems.

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Keywords Natural conditions of culture · Human impact on nature · Timeline · Critical media studies

1 Introduction

The analysis of the way in which the physical environment influences cultural life is known as *environmental determinism*. Human nature, behaviour and culture are directly connected with environmental conditions and change, and vice versa. The targets of human development are linked with targets for the use of nature. Ecosystem services are ecosystem functions that result in human benefits (e.g. Herrmann 2016; Matthews et al. 2012).

Environmental history, including landscape history, reflects the interrelationship between human activities and the surrounding landscapes and nature, between resource use and well-being. There is nothing, no aspect of human life which is independent of the environment, of ecological conditions or ecosystem services. Moreover, extreme values and extreme events seem to be more relevant for the understanding of ecosystems, human behaviour and awareness than average values or everyday life (de Haan and Ferreira 2006; Gifford 2014).

History shows an increasing influence of cultural life on the physical environment, which does not imply that humans are becoming increasingly independent of the environment. However, as the market expands from local to global the meaning of regional and seasonal products decreases, to such extremes that you can buy bananas in the Arctic.

The terms *culture*, *landscape* and *environment* have different etymological roots and they are of very different ages (cf. Flint and Murphy 1997, also for the following definitions).

The word *culture*, from Latin *cultura* is related to tilling the land and was already used by the ancient Romans in the sense of agriculture.

The word *landscape* was first used in Central Europe during the Middle Ages. It originally related to the people in rural areas. At this time the term *landscape* referred to people and families living alone or in small groups far from urban areas, rather than to their surroundings. The meaning of the term has since changed and today a landscape comprises the physical structures and habitats typical of a certain region.

The term *environment* is relatively young (modern era). It has French roots and the meaning is the state or condition of the surroundings in which humans operate. In a broader sense, the term is also used for other kinds of organisms.

Cultural history, landscape history and environmental history all have different focuses and encompass different aspects of history. In the following, these different histories are used to focus on the cultural development which has developed as a result of a changing environment and past relationships between humans and the environment/landscape.

The central questions of this chapter are:

Which events and processes in the past might have been important for an understanding of the use and management of biodiversity and ecosystems today?
What does history tell us about the degree of freedom and constraints of humans in their environment?
Is the timeline of putative important events and processes in environmental history influenced by recent environmental perception and problems?
Did our perception of the environment change with the increased secularization of society?
How is environmental perception, including environmental stress and fear, connected with knowledge, social behaviour and risk management?

It is impossible to disentangle this complex issue in a short discussion, as it necessarily involves many different disciplines, including at least climatology, evolutionary ecology, biogeography, environmental psychology, ethics, disaster sociology, economy. This chapter can, thus, only attempt to provide an overview of the basic issues.

To answer the questions it is necessary to use empirical data. The following date specifications, and age or duration data represent recent knowledge. However, many time specifications have changed in recent decades and it is clear that many will have to be adjusted again in the future.

2 Environmental Effects on Humans and Human Influence on Nature

It is unknown when exactly humans began to alter the structure of landscapes. On the other hand, human influence was simply not possible before people actually occurred in a region. Thus, we can assume that the first important step towards the influence on different regions and ecosystems in the world was the migration and dispersal of humans.

Several million years ago early humans (*hominins*) evolved in Africa. Different species of humans dispersed to Europe, Asia and Indonesia between two million and 600,000 years ago and arrived in Australia, S America and N America c. 65,000, 33,000 and 12,000 years BP, respectively (Reed et al. 2004; Wood and Strait 2004; Wood and Richmond 2000; Macchiarelli et al. 1999). On the basis of their morphology, the ancestors of modern humans (*Homo sapiens*) were described as archaic species such as *Homo habilis, Homo erectus, Homo floresiensis, Homo neanderthalensis,* and others. It is now known that *Homo neanderthalensis* and *Homo sapiens* were living together about 60,000 years ago in the Middle East, and that they were able to interbreed. Modern humans carry traces of Neanderthal DNA and probably of other archaic humans in their genome (Green et al. 2010; Sankararaman et al. 2014; McCoy et al. 2017).

Thus, the terminology of *modern* vs. *archaic* humans has recently became a little outdated. Knowledge of the skull morphology and genetics of early humans does not allow any appraisal of their behaviour. However, the first archaic humans had smaller brains than more recent humans, which supports the assumption that they had a lower level of intelligence.

The oldest human artefacts date back to the time long before *Homo sapiens* occurred on Earth. Old stone tools such as axes dating back 3.3 to 1.5 million years have been found in Africa and the Middle East. Fire was used at least 0.2, but most probably one million years ago. Spears found in Germany are 300,000 years old, and digging sticks were used at least a couple of ten thousand years BP. Both might, in fact, have been used much longer but unfortunate conditions of preservation reduce the likelihood to find artefacts made of timber.

Rock paintings, beads and musical instruments from Africa and Europe are calculated to be 120,000 to 40,000 years old (James et al. 1989).

Stony material, fire, timber, shells, bones, teeth of sharks and colours were used to hunt animals, to procure food, to produce paintings, arts and most likely to reflect life. All these processes had a more or less strong effect on the local surroundings of the humans concerned.

Digging sticks can be used to excavate roots or other living material from the soil. They might easily also have been used to put seeds or fruits *into* the soil. This would not easily be verifiable to science. I hypothesize that planting and transport of propagules by humans is as old as humans' realization of the relationship between seed and seedling, and thus might be much older than the Neolithic Revolution.

In short, the influence of human activities on the structure of landscapes might be as old as the evolution of hominids, the use of fire or the oldest artefacts (cf. Conard et al. 2015; Brahic 2012; Roberts 2012; Sawyer and Deak 2008). Hunting of wild vertebrates can be linked with the oldest artefacts and it is very likely that humans in general hunted fish, birds and mammals wherever this was promising. Because humans normally hunt visible prey by day in open or half open landscapes, banks, shores, grassland, heath, steppe and light forest might have been favourable ecosystems for living and hunting. With the use of fire and lithic tools it would have been easy to open up the landscapes for hunting.

The wolf was most probably the first domesticated animal, domesticated 4 to 26 thousand years earlier than any cultivation of crops. Nobody knows the exact reason for this early domestication. However, from the behaviour of wolf and dog it seems possible that these animals were seen as companions, signal transmitters in the case of enemies such as wild wolves or foreign human populations, as facilitators for hunting, or as herding dogs. Could it be possible that humans were pastoralists before agriculture and settlement? There are many possible ways, such as following wild flocks and breeding domestic animals in fenced fields, in which pastoralist systems can be developed. During any of these processes a wolf or dog could have been a considerable help (cf. Pierotti and Fogg 2017). It has been shown that in sub-Saharan Africa cattle-assisted nomadic hunter gatherers took meat, milk, bones and skin from domesticated animals long before they began to cultivate plants (Neumann et al. 2003).

It is clear that arable land, ploughing and shifting cultivation require settledness; as shown, among others, by the Sami in Scandinavia, it is possible that pastoralism does not. Thus, it is likely that pastoralism developed, with wolves or dogs as the principal supporter and ungulates as a source of food and materials, thousands of years before agriculture was developed.

Long-term bidirectional gene flow and the exchange of pathogens are assumed for almost all domesticated animals and as long as wild counterparts live in the surroundings. To date, domestic animals such as pigs, geese or chickens can become infected by the migration of wild animals. Hence, livestock owners had, and still have, a serious interest in keeping wild animals away from domestic ones. This might have been a strong reason to eliminate wild horses, sheep, goats, and others.

Agriculture—the Neolithic Revolution—which enabled sedentary food production is an invention of the Holocene and a warmer climate after the Pleistocene. It is assumed that agriculture developed in six to eight regions on earth independently (Herrmann 2016; Diamond 2003).

The origin of agriculture has been dated from 11,000 to 6000 years BP in SW Asia (e.g. wheat, *Triticum dicoccum*, and other cereals), N China (millet, *Setaria italica, Panicum milleaceum*), Papua New Guinea (taro, *Colocasia esculenta*, and yam, *Dioscorea* sp.), and Mesoamerica (e.g. maize, corn, *Zea mays*).

Changing of behaviour with the development of modern life is dependent on three important bundles of processes. The first is connected with the use of fossil fuels, the second with the use of chemical compounds such as fertilisers and pesticides in landscapes and waters. The third is the use of modern technologies. The increasing use of fossil fuels and chemical products has heavily impacted the environmental conditions of many landscapes over the last 300 years and particularly in recent decades. The application of modern technology has led to an increase in traffic and productivity. Until the eighteenth century, these three aspects combined barely increased productivity at all (in contrary to the time afterwards, cf. Fig. 1).

Is it possible to estimate which ecosystems were primarily used or influenced? Ecosystems had to be used from the very beginning to obtain food, energy and security. Food most likely came from collecting living material such as fruits or roots, from fishing, hunting vertebrates and collecting invertebrates. During this period there might have been no great difference between the influence of humans and that of other large ecosystem engineers such as elephants, rhinoceros or wild megaherbivores on the landscapes. Animals were hunted in rivers, along the coast (fish) and in many ecosystems such as shallow waters, in lakes and rivers, in grassland, savanna, steppe, woodland, and forest. Fire, spears, digging sticks and other wooden tools were produced of timber which could have been collected e.g. in any landscape where there were trees and bushes. It was much easier to hunt animals in open or semi-open landscapes than in a dark forest; even today hunters open up small windows in the forest to enable them to get better shots. In the past, and why not for many ten thousands of years, humans have been interested in half-open or open landscapes rather than dense forests.

Ecosystems that were not used until a later date might conceivably have been screes and rocky habitats on high mountains, deserts, pelagic and deep sea ecosystems. However, this assessment is a product of speculation rather than verified by empirical data. Today, the deep sea, the ice caps at the North and South Poles and the

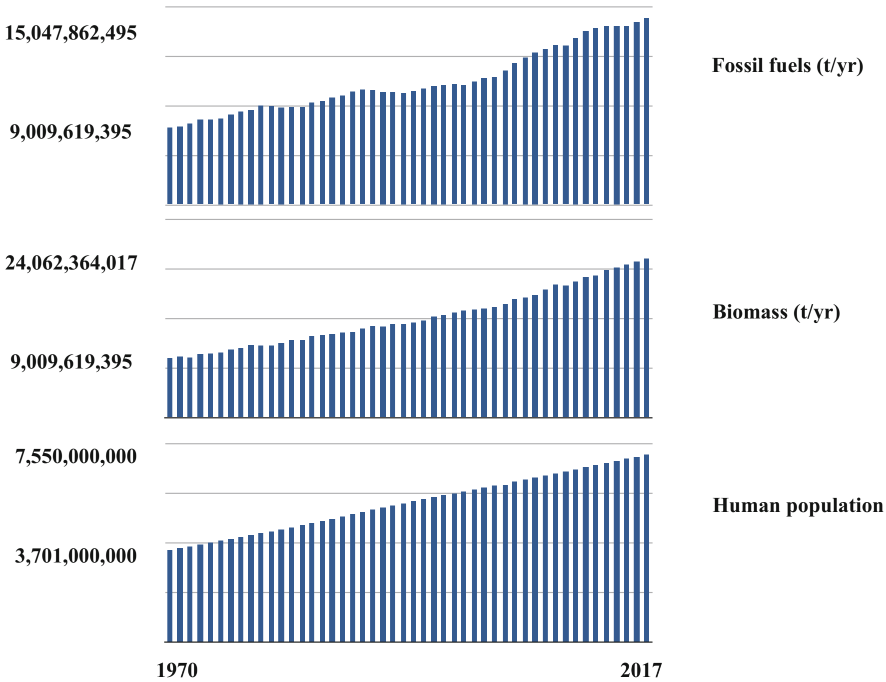

Fig. 1 Increasing human population (number of people) and use of fossil fuels and biomass (tons per year) between 1971 and 2017 (redrawn according to raw data in worldresourcesforum.org; accessed 30.11.2018, and https://www.census.gov/data/tables/time-series/demo/international-programs/historical-est-worldpop.html; accessed 28.03.2019)

deserts are not inhabited by stable and reproducing populations of humans. Most islands and archipelagos in the world have not been inhabited for more than a couple of hundred, or thousand, years (Herrmann 2016).

Clearly, migration, population growth and intensification of food production have led to dramatic changes in a variety of ecosystems over the last few centuries. Cities and other urban habitats are the most artificial ecosystems and have no counterpart in nature, and agricultural and horticultural land is a semi-natural to artificial series of habitat types. According to FAO statistics (FAO 2016) increasing agriculture remains the most significant driver of deforestation. On the other hand, growing cities replace former arable land, with the effect that arable land has to move. Dramatic changes in recent decades in the quantity and quality of most grassland ecosystems in the world are directly related to change in use and indirectly to the intensification of timber and food production, and to atmogenic input of NO_x and NH_4^+. Grasslands have declined in quantity due to the conversion to cropland, the planting of trees or succession caused by a reduction of pastoralism and abandonment. The migration of wild and domestic herbivores is increasingly restricted by fences and fragmented landscapes and by the housing of domestic animals in huge stables. In parallel, human activities on foot have decreased heavily over the last few centuries and have been replaced by driving, shipping and flying.

Three periods in the extinction of biota can be linked with human history and behaviour (Table 1; see references there).

The first extinction period occurred between 132,000 and 8000 years BP. During the late Pleistocene and early Holocene c. 200 species belonging to 100 genera of predominantly large mammals (>40–50 kg) became extinct on all continents except Antarctica. In many cases, this happened long before, and outside of, regions where agriculture occurred. Climate change and overkill by hunters or a combination of climate change and hunting have been discussed as the main factors involved. However, there is no evidence that climate change alone might have been responsible. Human arrival at landmasses and migration, appear to be the most important causes of these extinctions on continents (Louys et al. 2007; Burney and Flannery 2005; Martin and Klein 1989). The transportation and introduction of pathogens might also have affected the extinction of large mammals (Lee 1997). Sandom et al. (2014, page 1) showed "*that the severity of extinction is strongly tied to hominin palaeobiogeography, with at most a weak, Eurasia-specific link to climate change.*"

The second period began c. 1500 AD and was a result of shipping across the oceans and the exploration of islands and archipelagos worldwide. One of the main factors was the introduction of predators, omnivores, herbivores, plants and pathogens such as rats, pigs, goats, dogs, cats, crops, ornamental plants, bacteria and others which were able to simply devour whole populations, and in combination to totally change the structures of landscapes.

The third period began as international and intercontinental trade and traffic in the twentieth century exploded (Federico and Tena-Junguito 2016). The main reasons for species extinctions according to the IUCN Red List (iucnredlist.org, downloaded fifth Oct. 2018) are habitat destruction, agriculture, aquaculture, biological resource use, and invasive or other problematic species including dispersal of viruses, bacteria and fungi. Diverse groups of plants and animals, including invertebrates, became extinct after the Second World War, some also earlier. Amphibians have been declining dramatically since c. 1980 due to human dispersal of pathogens and diseases such as chytridiomycosis.

The effects of these periods were dramatic, not only for species compositions and the existence of certain species but also for ecosystem properties. For example, the whole biomass of wild land mammals before the Quaternary Megafauna Extinction (c. 0.02 Gt C) is estimated as sevenfold higher than it is today (0.003 Gt C). The global biomass of humans and livestock (0.16) by far surpasses a recent estimate of the biomass of wild land and sea mammals of c. 0.007 GT C (Bar-On et al. 2018).

The timeline (Table 1) shows the increasing influence and pressure of humans on nature, the increasing use of space, and increasing intensity of use. It does not show a declining dependence of humans on their physical environment since basic requirements have not changed.

We do not have appropriate information about the psychological relationship between humans and nature in prehistory. The idea that humans once lived in harmony with nature is a hypothesis without any empirical foundation.

Table 1 Examples of historical events and processes

Time/period (before present or AD)	Landscape-culture events, trends and activities	References
3.3–1.5 Mio	Evolution of the genus *Homo and other hominins.* Ancient humans most probably lived as hunter-gatherers in semi-open landscapes of Africa. Stone tools have been found in Africa and the Middle East.	Ghosh (2015)
1.8 Mio–600,000	Humans dispersed to Europe, Asia and Indonesia. Opening of landscapes using fire and stone tools became possible at least one million years ago.	Poschlod (2015) and Ghosh (2015)
300,000	Use of spears, artefacts from Schöningen in Germany.	Julien et al. (2015)
170,000	Early clothes used by modern humans in Africa.	Toups et al. (2011)
132,000–8,000	Megafauna extinctions most probably related to human activities; c. 177 species of mammals became extinct during the late Pleistocene and the early Holocene.	Sandom et al. (2014)
36–14,200	Domestication of ancestors of the gray wolf to dog long time before Neolithic Revolution. Humans in W Asia gathered and consumed wild cereal grains 23,000 years ago.	Germonpre (2009), Clutton-Brock (1995), Nadel et al. (2012), Piperno et al. (2004)
16,000–10,000	Migration of Paleolithic hunter-gatherers from continental Eurasia across Beringia and N America to S America.	Goebel et al. (2008)
9500	Black Sea deluge. There is still debate as to how fast the Black Sea became flooded. However, there are many legends about related flood disasters.	Aksu et al. (2016), Poschlod (2015)
1500 AD–today	81 mammal species have become extinct in modern times, many of them within the last 200 years, particularly on islands and archipelagos. The introduction of neobiota such as the rat and other predators was one of the main reasons for the extinction of indigenous animals on islands. Erosion of traditional knowledge, increasing influence of scientific information	IUCN (iucnredlist.org; ass. 2018/4/13) and Gleick (2012)

(continued)

Table 1 (continued)

Time/period (before present or AD)	Landscape-culture events, trends and activities	References
1816 AD	Year without summer. Mount Tambora volcanic eruption in 1815 in Indonesia caused severe temperature decline, failure of crops, hunger and death to people of the Northern Hemisphere. Mean summer temperature fell partially by 3° C because of the dust in the atmosphere.	Stothers (1984)
Eighteenth to twenty-first century	Romantic movement, environmental movement. Industrial revolution with strong regional pollution of air and water in cities and industrial areas, nature conservation movement, environmental laws, green politics, international conventions (CBD), environmentalism.	LaFreniere (2007) and McCormick (1995)
Since 1980	Amphibian decline caused by Chytridiomycosis and other pathogens. The fungus Batrachochytrium dendrobatidis and viruses were dispersed by humans likely propelled by the trade of animals, and it is now clear that climate change is not the primary driver of the decline in amphibians.	Miller et al. (2018) and McCallum (2007)
Twenty-first century, first 20 years	The human population is still growing accompanied by hunger crises, death and migration. Widespread discussion about climate change and social consequences caused by global warming and sea level rise. Many environmental disasters are interpreted to be linked with global warming. To date, no package of measures has been implemented to effectively reduce the biotic crisis and damage to ecosystems at a global scale. Examples of successful measures are related to local, regional, national and sometimes supranational scales.	cf. IPCC (2014), Myers and Knoll (2001), FAO statistics and National Reports (CBD) on the internet (downloaded e.g. 10/2018)

However, while discussing important environmental conditions and processes the human population and the mean lifespan of humans continues to increase, accompanied by hunger crises, death and migration.

Environmental ethics, *environmentalism*, *nature conservation* and *green politics* are relatively new terms. Related activities, money invested and percentage values of protected regions have increased in almost all countries in the world in recent decades.

The history of human influence on ecosystems and species compositions, on the risk and rate of extinction of diverse species, and on effective biodiversity conservation management shows a growing interest not only in the field of ecology after the Second World War but also in the recent debate about the meaning of historical events and continuity, about climate and land use change. The evolutionary and historical aspect is also receiving more and more attention in scientific fields such as ecology and biogeography as a means of better understanding ecosystems and species assemblages (LaFreniere 2007; Herrmann 2016; Brooks et al. 2006; Martin and Klein 1989).

However, the current objective ecosystem and biodiversity crisis is accompanied by a social crisis of insufficient scientific reflection and education.

Insects, for example, are declining in quantity (1), the number of pages in school books and other teaching material about insects is decreasing as well (2), and natural history and taxonomy are also declining as scientific disciplines at the universities (3) even if public awareness of the biodiversity crisis, including insects, may be on the rise. The crisis of taxonomy and field ecology/natural history has to do with the dynamics and development of science at the universities. This dilemma pertains to other disciplines as well (Bacher 2012; Tewksbury et al. 2014; Bik 2017; Koch 2019).

3 Discussion and Conclusion

The description of historically important events and processes and the scientific reflection on nature-culture relations of the past is strongly influenced by recent environmental movements, awareness and perception, including fear and beliefs. The related biases are discussed with respect to *constructivism, confirmation bias* and *media theories* (e.g. Kempf 2006).

Modern environmental history has a strong focus on climate change, which is often described as the biggest problem of the human community in the twenty-first century.

Water and air quality or the biodiversity crisis are also picked out as central themes in general scientific discussions and media from time to time. Landscape history focuses on regional landscape ecology and landscape archaeology, mainly of rural areas. Thus, both the media and scientific publications pay much less attention to ecosystem change than to climate change.

Moreover, there is no guarantee that the picture of environmental history painted here can provide the most important processes and events to understand the present or to look into the future.

History has not yet shown any globally effective package of measures to protect the atmosphere, hydrosphere, lithosphere, pedosphere or biosphere at a global scale (Myers and Knoll 2001), even though international rules such as the Human Rights, Agenda 21, CBD, agenda of the IWC (International Whaling Commission), and others have been implemented (United Nations 2014; cf. Fig. 1).

Thus, management planning and conservation practice will most likely also be more successful if working directly on a project with a clear goal and at a local to national, or in some cases, a supranational scale.

I hypothesize that problems of water quality, quantity, availability, drought, severe floods, tsunamis, the damage and reconstruction of ecosystems, and diseases linked to the environment have been and will be the most severe environmental problems for humans, and humans are the most severe problem facing the survival of biodiversity and ecosystems. For the survival of ecosystems and biodiversity, intensification of and changes in land use pose the greatest problem. A small percentage of endangered species are also affected by climate change and severe weather. Thus, climatic factors can worsen the environmental problems facing biodiversity and ecosystems.

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Nature-Culture Dichotomy and Environmental Consciousness: Do We Fear the Right Things?

Carsten Hobohm

Abstract Basic convictions, political regulations and cultural behaviour based on tradition and communication influence the management of the environment, and as such are an important corridor of power affecting natural habitats. This also depends on whether a disaster is seen as blow of fate, natural and irremediable, or as a problem caused by humans (Nature-Culture Dichotomy).

Nature and culture are often used as antipodes. What is right with the Nature-Culture Dichotomy? Independent of the question of whether our behaviour towards nature is respecting ecological conditions and ascribing the very right of existence of other biota as well, we often feel and behave like beings outside of the nature, and belonging to the inside of houses, civilization and cultural life.

What is wrong with the Nature-Culture Dichotomy? Currently, many scientific contributions on the nature-culture relationship argue against the dichotomy, attempting to overcome the divide with the goal of harmonization, or describe a trajectory beyond the dualism. Arguments against the Nature-Culture Dichotomy are related to considerations in the social sciences, environmental ethics, human ecology, but also in neurobiology. One general concern is the difficulty finding a clear cut between the two realms. However, the main criticism may be that the Nature-Culture Dichotomy is implicitly driving and reducing the scope of assessments and value measures to the artificial side, leaving nature amoral.

The question is, which events and processes of the environment and landscapes in the past might have been important for the understanding of the present? Does survival and organization of the future depend as much on perception and memory, on educated traditional and scientific knowledge, on the explanation of disasters including religious and spiritual interpretation, and human behaviour in disaster situations?

A growing world population provokes serious threats to ecosystems and species worldwide. The species decline continues even if the activities of diverse NGOs,

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private initiatives and governmental organisations have already prevented the extinction of certain endangered species at local to international scales.

The perception and interpretation of the environment changed during the secularization, and in modern times from a religious dominated to a scientific framing. Furthermore, during a very short time period the communication channels changed due to the development of print media and later modern digital technologies. The amount of available information, including scientific knowledge, has simply exploded across the globe during recent decades.

Handling and filtering of information in combination with a stronger focus on ecosystems and biodiversity will be a key for the success of biodiversity conservation management in the future.

Even if it may be impossible to exclude environmental disasters completely, the interplay between environment and environmental consciousness resulted in technological and other solutions to reduce the risk for humans during modern times.

Nevertheless, the permanent adjustment of environmental consciousness and relating behaviour as a precautionary principle between environment/ecosystems and survival of the biota has the potential to reduce the threats for biota as well. The risk management may profit from increasing attention on slowly changing human activities and environmental conditions, and from revaluation of natural attributes.

Do we fear the right things? The communication of danger signals from the environment, and risk assessments, were useful historically and are still useful even if only a small proportion of disaster forecasts become reality. Thus, the behaviour must always be adjusted in relation to our knowledge and readiness to calculate a risk. The answer is clearly yes; in many cases we fear the right things.

Additionally, we are able to forecast dramatic events from very small danger signals by using a combination of fantasy and logic. Furthermore, if death is a matter of more or less regular stochastics, like the number of killed people by car accidents, then we are also able to slow down the awareness, because the biology of fear does not allow intensive fear for a long time. We are able to fear terrorism much more than car accidents even if the death toll is much smaller. Thus, in this case the answer is no; we do not fear the risks adequately.

As a consequence of the psychological predisposition humans are sometimes overcautious and sometimes heedless.

To summarize, our environmental consciousness is the result of an interplay between our evolution, environmental history, communication about disasters, and social behaviour. As such it cannot guarantee avoidance of future environmental disasters. This might also be related to the playful and experiment-friendly side of humans, and the simple fact that certain regions or environmental conditions are at the same time both beneficial and life-threatening.

In general, awareness and fear are directed to survival and avoidance of pain. Thus, environmental conditions of ecosystems and the survival of natural habitats and species diversity on Earth are not the central goal of our environmental consciousness even if further losses have the potential to limit the cultural life and well-being of humans.

Keywords Environmental catastrophes · Nature-culture dichotomy · Fear · Awareness · Communication · Scientific reflection · Precautionary principle · Climate change

1 Introduction

It is a great challenge to protect biodiversity and ecosystems in the face of an ever-growing and resource-consuming population of humans. Environmental awareness is the result of the interplay between human evolution, environmental history, and societal relations to nature. How important are disaster-memory and the Nature-Culture Dichotomy in the context of environmental management and risk prevention?

Many conditions of ecosystems and biodiversity are changing slowly if not imperceptibly. It can be assumed that many species already have been eliminated which were never recognized by science. Thus, the relating processes are invisible for humans even if humans are causing the loss. Important features of ecosystems may change with little scientific recognition. An example may be changing species compositions of microorganisms in soils and water sources as a result of an increasing transfer of certain chemical substances such as nitrogen from the atmosphere. The relating bacteria, fungi and other microorganisms are key species to ecosystem functions; however, the scientific knowledge about microbiomes is still rather limited (Klironomos 2007; Rashid et al. 2015; de Menezes et al. 2017). The following consideration is based around the question—is environmental consciousness reflecting recent environmental challenges and risks properly? Furthermore, it is an open question, whether the damage of ecosystems and biodiversity might have stronger impacts on human cultures, wellbeing, and survival than we are able to estimate today. This contribution reviews the meaning of our environmental consciousness with regard to the environment on the one hand and management effort on the other.

Why should a contribution about major problems of ecosystems and biodiversity take part in a rather theoretical debate about the so called *Nature-Culture Dichotomy*, *Nature-Culture Dualism, Nature-Culture Divide or Nature/Nurture Dichotomy/ Dualism?* All over the world we can directly observe destructive exploitation in nature, damage to habitats, species decline, a fast-growing human population which is getting more and more nervous, global heating, not only of the atmosphere, resulting in dystopia. Today we face very concrete ecological and social disasters, and time is running out to solve multifaceted environmental problems. How might such a theoretical debate be related to practical consequences for the environment at local, regional or global scales? Furthermore, if the nature of humans enables destructive behaviour, and if humans are able to destroy their own conditions necessary for life, how might the discussion about the nature-culture relationship be relevant?

The reflection of where we come from might be helpful for the answer to the question about where we want to go. With this contribution I would like to promote the hypothesis that the nature of humans is a combination of both natural and cultural components (1), that the natural component in our behaviour is not absolutely determined, (2) and the cultural component is not totally free, (3) that the influence of our natural surroundings on cultural behaviours, the nature of our cultural behaviours, and the cultural influences on our natural surrounding are very important aspects for the evaluation of perspectives, (4) that humans are part of the ecosystems where they are walking and working, (5) and that the influence of humans on ecosystems, species compositions, species, and populations, must not be judged as negative in every case according to our own values and purposes.

Nature and culture are part of both humans and the environment.

And I want to pronounce that the extinction of any small insect that never has been recognised or described by science, independent of the question of whether we have used it or not, can be assessed as cultural loss, loss of values, knowledge and possibilities, of colours, forms, and aesthetical reflection, of a part of the evolutionary history and of our cultural future, and even if the loss of this species for the ecosystem as a whole might be negligible.

Central questions are:

How is environmental consciousness influenced by the biological constitution of humans as result of the evolution?

What is the meaning of *nature*, *culture*, and *Nature-Culture Dichotomy*?

How is our basic conviction of responsible management of nature and the environment influenced by the environmental history?

What are the influences of environmental tragedies, traditional knowledge, religion, science, communication and media on recent perception? How did the perception of the environment change during secularization and modern times?

How is the environmental behaviour, including risk management, connected with the ecological knowledge and environmental consciousness?

2 Environmental Disasters, Creeping Changes and Perception

There is debate about the differences between the terms *hazard, catastrophe* and *disaster* with respect to the influence of humans. Some events are natural, others are man-made, and the effect size in general is influenced by human technologies and infrastructure, risk prevention strategies, and health care. However, there are also disasters or catastrophes for other species on Earth, again human-caused or not. All these terms that have dramatic effects for humans or other species are used synonymously in the following with respect to the debate of the Nature-Culture Dichotomy.

The Mesopotamian cultures disappeared during the third millennium BC. To date it is still unclear if the main reason was war, climate change, change of the hydrological system, depletion of soils, salinization, or a combination of these (Kuzucuoglu and Marro 2007; Diamond 2011).

The deadliest environmental disasters in history comprise, for example, volcanic eruptions and tsunamis that eradicated the Minoan culture around 1500 BC, the Antioch earthquake in 526 AD and the Aleppo earthquake in 1138 AD, but also homemade disasters such as the heavily polluted air in London many decades and a few centuries ago or the Bhopal disaster in 1984 (Fortun 2009). Tens of thousands or even more than a hundred thousand people died because of the Lisbon earthquake in 1755 and flood catastrophes at the German North Sea coast in 1219, and 1362, for example. During the great Chinese famine in the years (1958) 1959–61 (1962) up to 43 million people or more died. Today, this extreme disaster in history is interpreted as a combination of political decisions and unfortunate weather conditions (Becker 1998; Demeny and McNicoll 2003).

In different parts of the world, and not long ago, sacrificial rituals were part of different cultures to achieve harmonization with gods and to ensure survival and profit from the nature. This might have been normal during the past, including elimination of triebes (genocide), and can be called a long lasting disaster today.

Reports and legends about the reflection of nature and awareness of environmental disasters are going back to the ancient world (see Heidegger 1998). Recently, the number of disaster narratives carried by the media are on the rise worldwide. Therefore, it is not easy to detect whether the number of environmental disasters over time is also on the rise. Furthermore, the feeling of '*what a disaster is*' has changed continuously along with technological developments and the changing compositions of human activities.

Which environmental problems will increase in the future? This question is a universal one, which was important everywhere in the past too. However, the flow and amount of information is increasing immensely over time (e.g. Gleick 2012).

Environmental events like a wildfire in the landscape can only appear if certain environmental conditions are realized—drought, flammable material, and so on. However, the effect size does not only depend on environmental conditions such as the amount of litter and wind speed combined with drought but also on the way how humans observe, perceive, evaluate, organize the risk prevention and manage the environmental disaster including effects afterwards (Fig. 1).

The fire itself might be the result of lightning (nature) or of a pyromaniac (crime). In certain landscapes it is a normal and natural event caused by lightning and enables a rich biodiversity to live there, e.g. in the Cerrado in Brazil or in Mediterranean climate regions of S Africa, Europe, SW Australia or SW North America. Without frequent fires in these regions the biodiversity would dramatically decline. Supression of natural fire regimes can result in fires that get out of controle. This is the concordant message of ecological science today. However, this finding is a relative modern one.

In these and other landscapes a wildfire may destroy houses or kill people. Furthermore, in many landscapes, e.g. in the Mediterranean or in California the

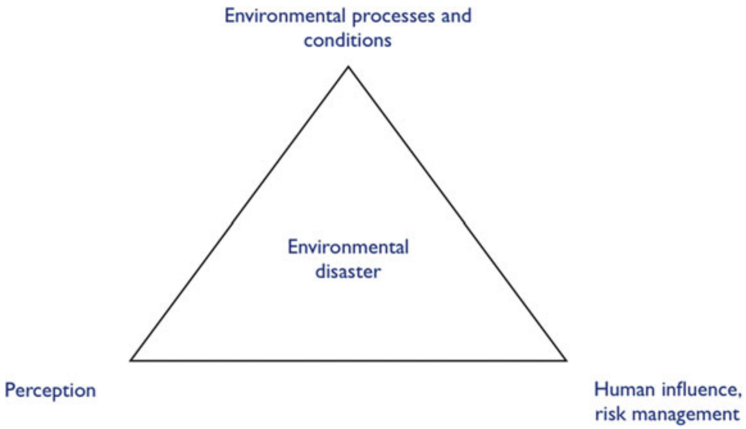

Fig. 1 From environmental processes, perception, and risk management, to the (reduction of) a disaster for life

risk of fire has artificially been increased by dense plantations of trees such as eucalypt, pine or other species which are characterized as pyrophytes (fire-plants) because they easily burn and profit from fire. Thus, a burning landscape might be seen as natural and important event or as a disaster. The management depends much on the way we think about the environment and organize the risk prevention.

Consequences after fire in a landscape may be

1. to invest in money and fire brigades,
2. to punish the offender,
3. to change the composition and density of trees through forest management,
4. to organize pastoralism and open the landscape,
5. to artificially increase the number of local fires and thus to reduce the flammable biomass, litter in the landscape, and the risk of a mega-fire event.

These and other actions, for example religious rituals, might have the intention to harmonize the relationship to God and nature or to lower the risk of a wildfire.

3 Environmental Psychology and Biology of Fear

Human evolution including the emergence of bipedalism—freeing hand and thumb—and encephalization—increasing brain size—enabled recent human behaviour. Human behaviour on the other hand is controlled in part by emotions and logical reasoning, and by right and wrong decisions.

Environmental psychology is a discipline focusing on psychological transactions and conditions between physical setting and social life. Willy Hellpach (1911, 1939) might have been the first scientist analysing the influence of weather and climate,

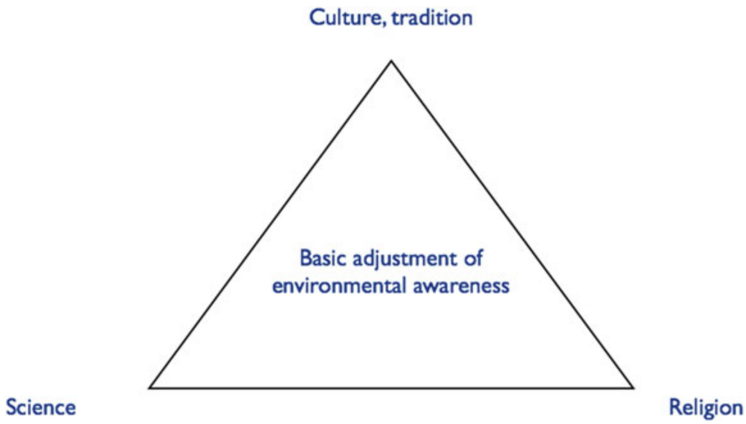

Fig. 2 From religion, culture/tradition and science to the conviction of how to interpret the environment and organize the risk management

soil and landscape on the human soul. What he described as relationship between *landscape and soul* (in German, Hellpach 1939, 201 ff.) is not much different from *place identity* in modern psychology (Hague and Jenkins 2005; Gifford 2014). The psychological constitution is a product of natural and cultural aspects. It is conducted by diverse influences including spirituality. Furthermore, traditional systems of stewardship are obviously important for the wellbeing of native plant and animal communities on the one hand and protection and conservation of biodiversity at local scales on the other (Nilayangode et al. 2016; Kumar et al. 2016).

Therefore, the question to be answered is—how is our environmental consciousness influenced by events in the past, and in itself influencing the risk management?

The perception, interpretation and analysis of the environment including disasters and risk management is influenced by science (logic, empiricism), religion (theocentrism, pantheism) and/or tradition (e.g. indigenous knowledge, cultural moral system, education and learning, spirituality; Fig. 2). The configuration of our basis adjustment is important for the spectrum of our decisions and reactions. In many cases the answer to an environmental problem can be an objective solution based on scientific facts, it can be to fight, fatalistic, a religious ritual, or an escape. Often the problem is interpreted due to the question of whether the disaster is a *natural* one and probably irremediable or caused by humans (nature-culture divide).

Man-made disasters are often more assessed as being problematic than natural disasters. However, risk prevention and risk management today can operate with both groups in a similar measure.

A phobia can be defined as irrational fear or unsubstantiated aversion. Do we fear the right things or do we ignore the important things? And how did the perception, guided by adaptation through survival and evolution, communication, education, learning and disaster memory change during the past?

Fear, a dramatic feeling of proximity, is defined as the "*intervening variable between sets of context-dependent stimuli and suites of behavioral response*"

(Adolphs 2013, 1). Like all other emotions, the biological constitution was formed by our evolutionary history (Sabyasachi 2007; Adolphs 2013). The goal of fear in most cases during the past was simply survival of the individual or group, whereas the same biological constitution now plays an important role in social communication and the use of technologies. However, the decision to fight, to escape or to react in a certain way often has to be a rather quick one. And the decision may be wrong.

Threats triggering fear can be concrete and indefinite as well. A spider or snake may represent a direct threat. The bad smell from deteriorated food or the noise of a bear may be alarming. However, the combination of unpredictability and inescapability boosted by alarming communication can cause strong fear even if a person did not get any direct signal from the environment and even if this person is outside of the risk. If the background of fear is rumour then a fear economy can easily use the situation and strengthen the fear through alarming propaganda. Emotion is driving the market and the market is driving emotions (Rick and Loewenstein 2008; Bandelj 2009; Read 2009).

4 Nature, Culture, and Nature-Culture Dichotomy

The term *nature* goes back to ancient Roman times and comprises the physical world of the universe, referring to the Latin word *natura* which literally means *birth*. Human birth obviously are related to fate and pain which could hardly be altered by cultural behaviour. *Culture* from Latin *cultura* refers to agriculture, crop cultivation, ploughing. *Nature* describes conditions outside or independent of human's options for action, *culture* is related to human's possibilities, ideas, values and programmes. However, the difference between the two is part of the debate in all sciences where nature and culture are connected or clashing. At least today, when evolutionary principles and basics in neurobiology are common knowledge, the border between nature and culture is crossing everybody's identity and humankind in general.

One of the main questions about the relationship between nature and culture is focused on the degree of freedom and the constraints. Responsibility and accountability, religious and scientific/rational orientation, spirituality, emotions and aesthetics, outside or inside of nature and outside or inside of artificial buildings and cities are items of relating considerations (cf. e.g. Greenwood and Stini 1977, Jonas 1979, Böhme 2002, Milton 2002, Brady 2003, Poschlod 2017).

Humans lived in harmony with nature as long as they lived in nature, as part of the ecosystem and the food web. The alienation from nature increased continuously with increasing settlement, cultural and technological development, with the replacement of natural ecosystems by semi-natural and finally artificial habitats and megacities, and the replacement of the food web with international trade. The mechanistic worldview replaced the cosmos as a living organism. Stories like this have often been told (Morgan 1908/1979; Gehlen 1961; Merchant 1980). However, we almost know nothing about the intellectual world of humans living before ancient Chinese, Egyptian and Greek times and their writings (Toynbee 1979).

Was the relationship with nature predominantly fearful or amicable? Or was the relationship similar to the one of modern humans, with a combination of both positive and negative emotions and connotations? Which aspects of nature did people in former times cherish and which did they eliminate? Were humans during the Stone Age able to enjoy the beauty of a flower? What was manageable and what was resignation to fate? How was the system of ethical values arranged with respect to the natural environment?

In general, basic elements of reflection and reasoning during the past might have been the same as today. Realism and quasi-scientific recognition comprise observation, logic, trial and error, experimentation, induction and deduction. Interpretation and spirituality, including religiousness, comprise doubt, scepticism, belief, and imagination. However, consequences and rituals might have been totally different. Not long ago, cannibalism, sacrifice and the acceptance of punishment were conducted by religious cosmology, as part of the cultural interpretation of nature.

During the Middle Ages and modern pre-Darwin times the Islam, Judaism and Christianity played a powerful role in the Middle East, the Mediterranean and the western world. The interpretation of the present, and recommendations for tomorrow, including confession and repentance, was a matter for priests and churches. During this time, there was no good reason for the assumption that humans evolved together with other apes from the same ancestors. The relation to nature was dictated by danger and fear, pain and hard work. Thus, the interest in being part of nature must have been rather small. It can be assumed that a stroke of fate was related to decisions of gods rather than to scientific logic (Barnes 1965).

However, nobody exactly knows what the goals for action in the daily life of prehistorical times might have been. Nutrition, organisation of shelter, sexuality, and rest/sleep may be associated with the term *natural behaviour*. Music, arts and technology are normally attributed to *cultural behaviour*. However, what about communication? Communication and education are surely essentials through all times to guarantee survival and wellbeing of humans, by no means different from other intelligent mammal or bird species.

Is the narrow relationship between parents and babies more related to our nature whereas education in public schools and universities is part of modern social and cultural development?

The relation to the natural world comprises different aspects from *love/danger* to *innocence*. Antipodes such as devil as an omnipresent entity, and harmony including ecological equilibrium, have also been associated with nature. Harmony might have been an idea and leading concept for cultural behaviour through all times. Avoidance of harmony was personalised in the devil. Thus, nature served as template to what could be and what we do not want, but always outside of our scope for design.

Due to technical solutions, the imagination of ‘dangerous nature’ during former times was increasingly replaced by the imagination of harmlessness or harmony in the wilderness. Parallel religious interpretation was replaced by scientific explanation. Every day we can see movies about a perfectly organized natural world and impressive natural landscapes in harmony. Plants and animals are always perfectly adapted. The music in the background has sounds of a wellness centre, never underlayed with Jazz. If humans are part of films they play the role of destroyer or rescuer, always coming from outside.

Today, while the human population and civilization is growing, the aftermath of human behaviour on the environment is more and more negatively attributed. The powerful danger of nature for the cultural life of humans is replaced by the powerful danger of human activities for nature. However, this view is supported by plausibility rather than empirical data.

If the human population is still growing and in parallel the consumption of resources is still increasing, how might the discussion about the Nature-Culture Dichotomy under these circumstances help to find solutions for ecosystems and biodiversity? First of all, the discussion may show that there is no strict border between nature and culture. Cultural life is not restricted to humans and humans are by no means outside of nature, as evolutionary and neurological research shows.

The perception of nature as an unchangable, neutral and innocent entity, combined with the idea that humans are the most dramatic disaster for life on Earth, may lead to fatalism. However, a perception like this excludes the view (1) that nature is flexible, (2) cultural behaviour and human nature are two sides of the same evolutionary history, (3) and people should not leave nature for biodiversity conservation but instead use their cultural potential.

Protection of biodiversity and zero-species loss are clearly related to human behaviour. Self-reflection may help to find out what is possible and what is impossible.

What is right with the Nature-Culture Dichotomy? In the western civilized world, nature and culture are often used as antipodes. Islam, Judaism and Christianity support the view of one God outside and nature that needs to be guided and controlled by humans. Independent of the question of whether our behaviour to nature is respecting ecological conditions and ascribing the very right of existence of other biota as well, we often feel and behave like beings outside of the nature. Even if we accept our evolutionary history and natural components in our behaviour we can clearly see our own uniqueness, independent of the fact that all species on Earth are unique.

The term *natural* is used as demarcation line between different pairs of opposites such as real and ideal, pristine/wild and impacted, body and mind, natural and political/social, neutral and positive/negative, innocent and guilty. If natural nature is interpreted as a socially and politically neutral concept, then this has also implications for accountability. The principle can be applied directly or as underlying pattern, implemented in international regulations such as the Agenda 21, Convention on Biological Diversity, United Nations Framework Convention on Climate Change, EU Water Framework Directive, EU Habitats Directive, and the "*more or less hegemonic discourse of sustainable development*" (cf. Uggla 2010, 80).

What is wrong with the Nature-Culture Dichotomy? Currently, many contributions on the nature-culture relationship argue against the dichotomy, try to overcome the dichotomy with the goal of harmonization, or describe a trajectory beyond the dualism. Arguments against the Nature-Culture Dichotomy are related to discussions in social sciences, environmental ethics, human geography, and also from neurobiology and the theory of evolution. Meanwhile, indigenous ethnic groups get more and other rights than descendants of immigrants with respect to their traditions and behaviour in the nature.

One general concern is the challenge to find a clear cut between the two realms. The changeover from nature to human/culture is ambiguous (Gerber 1997; Nettle 2009; Mortenson 2011; Berque 2016; Escribano and De Penedo-Garcia 2018).

If nature is seen as the enemy, if we have pain or hunger caused by natural conditions, if we feel panic due to natural attributes, then it might be easy to fight against nature or certain natural attributes. If we accept that nature can be dangerous, ugly, or unfortunate with the effect that nature is not harmonious at all, then we can find bridges and transitions between nature and culture.

Furthermore, the decision of being responsible for only cultural processes and conditions, and to exclude responsibility for natural entities, would clearly reduce the scope of necessary actions.

As we consider overcoming the Nature-Culture Dichotomy, it begs the question—for what imagined or real guideline do we adhere to the terms and implications of nature and culture?

As short-cut answer, it can be concluded that humans currently represent emotions, behaviour, and decisions along both the Nature-Culture Dichotomy and the effort to overcome the dichotomy. We may observe what this will mean for environmental handling in the future.

5 Disaster Stories and Climate Change in Science and the Media

Invasive species have recently been seen as a huge environmental problem in many places on Earth (Ehrenfeld 2010; Stohlgren et al. 1999, iucnredlist.org). In contrast, many highly restricted species (endemics) are at risk of extinction. Thus, diverse activities are performed to fight against invasive species and to reduce the extinction risk of native species with a small population or range (e.g. Spatz et al. 2017; Hobohm 2014).

A clover fern which was found in a single locality in the Azores was scientifically described as *Marsilea azoria*, highly endemic to the Azores. However, this species was later identified as *Marsilea hirsuta* which is native and widespread in Australia. Therefore, the label changed from European priority species to invasive weed or alien (Schaefer et al. 2011). Clearly, this change of scientific taxonomy can have consequences for conservation measures in the Azores.

Another example of a changing scientific view comes from hares (*Lepus europaeus*) on Pianosa Island, Italy. The first scientific assessments came to the result that these hares could have been introduced by man for hunting purposes between 1840 and 1850. Thus, the eradication of this alien species was discussed in the framework of nature protection measures on Tuscany Islands. The eradication of invasive species is a general goal of diverse conservation activities worldwide. Later on, genetic analyses showed that the Pianosa hare population and the populations in mainland Italy are distinct. The Pianosa hares belong to the critically endangered subspecies *Lepus europaeus meridiei* and may have lived on the island since the late Pleistocene when Pianosa was part of the mainland. Therefore, eradication of hares on Pianosa Island is no longer a topic of conservation debate (Cabin et al. 2000; Carion et al. 2011; Gaertner et al. 2012).

The recent discussion about climate change is a good example of how controversial scientific positions can be. One reason may be that effects of prognoses are not fully realized yet. Furthermore, different environmental and social disasters can be linked to climate change or can be interpreted as independent events.

According to the media and scientists from diverse disciplines, climate change is the biggest global catastrophe or disaster for life, affecting human lives, health and cultures, and flora and fauna in the twenty-first century. Furthermore, climate change may have far-reaching physical effects in space and time. Interestingly, perceptions and emotions range from denial to strong fear of death. Sussman and Gifford (2014, p. 436) distinguish different types of *climate-change deniers* and *skeptics* who maintain their beliefs:

> "Fake experts are cited by climate-change deniers to show that no scientific consensus about climate change exists." (. . .) "Trend skeptics deny the trend of increasing earth temperatures. Attribution skeptics accept the trend but attribute it to natural causes. Impact skeptics accept that humans cause climate change but believe the impacts will be neutral or even beneficial . . . The "non-denier denier" or "greenhouse-lite" denier does not deny global warming outright, but denies the necessity to act. The non-denier denier is a construction of various special interest groups (such as oil and automotive companies) to discourage support for climate action."

Because of the negative connotation of the terms defined by Sussman and Gifford (2014), it can be assumed that the authors took a position when identifying groupings (Table 1, left column). However, *climate change deniers* and *trend skeptics* might also be called *continuity advocates*. Likewise, *impact skeptics* and *greenhouse lite deniers* should not be denigrated since all models of climate change are characterized by varying probability of occurrence (confidence levels). It is questionable whether members of social sciences s.l. including environmental psychology, who adopt the view of meteorologists and journalists, should create such one-sided terms for characterizing different positions. Thus, the second column of Table 1 shows the attempt to label members of a certain opinion with a more neutral title.

Not all *global catastrophe deniers* are members of oil or automotive companies. This type is represented by many scientists particularly in ecology, biogeography and life sciences. They are also dispersed across all other scientific disciplines. These people would never deny climate change because the nature of climate is change. There is no doubt from scientific facts that the lower atmosphere currently is getting warmer and sea level in average is rising worldwide even if the relative values differ considerably from region to region (e.g. Tapley et al. 2019). Clearly, members of this

Table 1 Orientation, belief and scepticism in the face of global change

Negatively connotated	More positively connotated	Explanation	References
Climate-change deniers, trend skeptics	*Continuity advocates*	Deny climate change, the trend of global warming and the increasing rate of severe weather	Sussman and Gifford (2014)
Attribution skeptics	*Naturalists*	Accept climate change but deny human causes	Sussman and Gifford (2014)
Greenhouse lite deniers, impact sceptics	*Optimists*	Deny the necessity to act because the effect of climate change is small or positive	Sussman and Gifford (2014)
Ecology ignorants	*Non-ecologists*	Assess the knowledge of environmental conditions and ecological processes of ecosystems as unimportant in the face of the global climate crisis	This contribution (original)
Non-denier, non-skeptics	*Believer*	Deny nothing and believe everything	This contribution (original)

group accept scientific findings such as the human contribution in the composition of greenhouse gases and rising sea level. Additionally they do not ignore negative effects for biota and social life caused by drought periods, storms, flooding, and other environmental hazards, independent of the question if these are man-made or not. However, global catastrophe deniers do not see any global disaster for humans via climate change.

The term *environmental catastrophe* is not only related to objectives in the environment, but in every case, describing the relationship between environmental events and susceptibility of the living organisms.

In general, causes and effects of hazards and catastrophes are regional events with a certain landscape-related probability of occurrence, and do not represent any global disaster (see Appendix A). This is important because terms like *global change* imply proximity for everybody and inevitability because of the impossibility of escape. Also the global mean sea level (GMSL) is an average value. Recently published maps of the sea surface and trends show regional differences. For example, high rates of the absolute (eustatic) sea level rise caused by warming have been detected for Indo-Pacific regions north of Australia since 1992, with values up to 10–12 mm per year (global mean 2–4 mm per year). In contrast, the sea level in the North Pacific Ocean actually fell during this period of time, independent of any vertical movement of the land (Parker 2014; Palanisami et al. 2015; Araújo 2016; Cazenave et al. 2018). However, the situation is more complicated than this because the sea level relative to the coast is also influenced by geological processes such as crust movements, as well as erosion and sedimentation, and human measures. Only relative sea level is concrete and relevant. Thus, a rising sea level and a further increasing area of land should not be seen as a logical contradiction (Donchyts et al. 2016).

Global catastrophe deniers cannot take the reading from trendlines (statistics) to a global disaster for humanity (cf. IPCC Reports). Most regions and ecosystems on earth with their inhabitants—humans and biota—do not suffer from global warming or climate change, and many regions are affected by other serious environmental problems such as habitat destruction and damage, pollution, and/or an increasing human use and pressure on their systems. This is the reason why we accept climate change as a challenge but cannot evaluate it as biggest environmental problem of the century.

Gifford (2014, p. 392) defines *environmental hazards* as "*events of unusually large magnitude, often unpredictable and allowing little or no preparation, that cause death or injury to many people, destroy much property, and disrupt many social and economic activities*." Examples are volcanic eruptions, earthquakes, bomb explosions, chemical spills, drought periods, floods, fires, and others. With respect to Gifford's definition and Harold Foster's *system for assessing the impact of environmental hazards and some stress scores for selected large events* (Gifford 2014, p. 405) climate change as a general and global trend can hardly be characterized as environmental disaster, hazard, catastrophe or calamity.

However, the scientific evaluation of the relationship between global warming and the constitution of ecosystems, biota and social life is complex, and the scientific reflexion is ambiguous at the moment. This might be the reason for the plurality of perceptions, interpretations, and opinions in this special case (see e.g. IPCC 2014, and the IUCN Red List, National Reports on biodiversity conservation in popular online media). Meanwhile a strong interpretation dichotomy developed across scientific disciplines leading to the proclamation of each party that the contrary position was non-scientific.

Furthermore, many people are aware of climate change, an increasing rate of hazards and risks that are in critical exceedance of tipping points. However, these people often overlook natural scientific facts, ecological processes and the meaning of ecosystems for human wellbeing and life (*ecology ignorants*). Climate change does not tell the whole story of environmental pressure on humans, flora and fauna.

I also want to introduce the opposite of any denier or skeptics which may be called *non-skeptics* or *non-deniers.* Credulous people often belong to this group. It might be fruitful not to have so many members of this group in social and scientific communities.

However, it is easy to denigrate members of any group of basic adjustment and it is more complicated to find a neutral label (attempt in Table 1).

Around eight billion people worldwide, and a growing life expectancy—isn't this a success story? One billion undernourished people, murder and increasing migration waves—isn't this a disaster story?

Whenever the media report a catastrophe or disaster the number of killed people is one of the most important for the scale of severity. Which are the facts and what do we fear most? Most people today die because of old-age and disease, cardiac insufficiency and cancer. However, which one, would we think, is the most dangerous risk in the world independent of these normal causes of death? Let us look at the top five of the most critical external problems for human's life according to statistics (United Nations 2019: World Mortality Report; regularly updated on the internet).

Number five goes to domestic animals such as dogs, cattle, horses, and elephants. Between 20,000 and 30,000 people are dying every year because of accidents and injuries from livestock and pets.

Number four is related to tsetse flies which transfer sleeping thickness—50,000 dead per year.

50–100,000 people are passing away every year as a result of snakebites—this is number three.

Diseases that are transferred by mosquitos are killing 700,000–1,000,000 people every year. Mosquitoes transferring viruses and bacteria are number two.

And the most dangerous omnivore—number five—is killing ten million people or more every year. According to Ritchie and Max Roser (2018) in 2016, more than two million people passed away because of terrorism (34,676), conflict (115,782), suicide (817,148), and traffic accidents (1.34 million). Landrigan et al. (2017) estimate that additionally c. nine million people are dying every year because of pollution and toxic substances in the air, water and food (based on numbers for 2015). Humans are the number one cause of death to one-another.

Just to compare, how many people are killed by lions, wolves, bears, sharks, earthquakes, wildfire, floods, and other effects caused by severe weather and global warming? All of them together result in much less than 50,000 dead people per year (in average). In 2016, 7059 people died as a consequence of so-called natural disasters (Ritchie and Max Roser 2018). According to the death toll of the 133 deadliest natural disasters (1815–2015) 39,517 people died on average each year. As the trendline in Fig. 3 shows this number is slowly decreasing.

Current reports about climate change forecast an increase in climate-related disasters per time-interval. Furthermore a positive relationship between global warming and the increase of severe weather is often assumed and justified by climatologists (e.g. IPCC 2014, 2018, 2019). Headings such as "*Severe weather more likely thanks to climate change*" (National Geographic, February 15, 2013) or "*Severe weather to increase in frequency & intensity*" (Reinsurance News, June 30, 2017) are frequent today in the media.

The amount of news that currently dominates the environmental debate, can be approximately summarized like this:

Climate change and severe weather are the greatest environmental challenge of the twenty-first century.

Climate change and severe weather are heavily impacted by human behaviour and resource use (e.g. production of CO_2).

Glaciers and permafrost are melting and the global sea level is rising.

The number of heat waves, droughts, windstorms, and flood disasters per time interval are on the rise.

We do not have much time to avoid a global catastrophe. There are problematic tipping points, and we do not have any backdoor because of the global dimension.

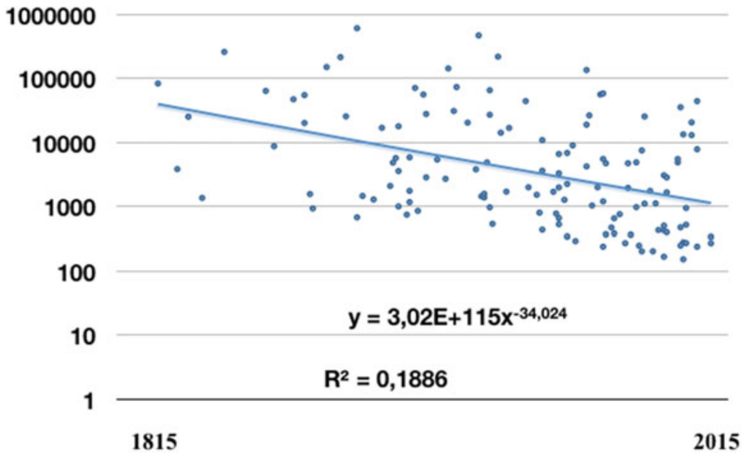

Fig. 3 Death toll in relation to disasters (N = 133), including volcanic eruptions, earthquakes, tsunamies, cyclones, hurricanes, typhoons, blizzards, avalanches/land slides, heat waves, and wildfires (see appendix and text for explanation and refs.). The figure shows an increasing rate of disasters (x-axis) and a decreasing death toll per billion people during the period 1815–2015 (y-axis)

Forests are depleted, deserts are growing, coral reefs are being destroyed and the number of species extinctions is increasing.

The IPCC report with reference to global warming of 1.5 °C, shows that the frequency and magnitude of heatwaves in most land regions, heavy precipitation events and drought in the Mediterranean, increased on a high or medium confidence level (respectively) compared with pre-industrial times (IPCC 2018). Figures 3, 4, and 5 are related to earthquakes and other natural events that already happened. The database of Figs. 3 and 4 is related to a list of 133 extreme disasters for the period 1815 to 2015 (appendix; cf. Anonymous 2008, Bradbury 2012, the whole time spanning 200 years and 2 months). However, this list is not complete since it is based on a long timeline, with different scientific methods, and communication channels. Disasters with less than 1000 dead people, and disasters caused by broken dams, diseases, and famines are excluded as the contribution of the environment in many cases is questionable. Figure 5 shows magnitudes and the trendline of earthquakes recorded between 1910 and 2009. The relating list is available at the homepage of the U.S. Geological Survey (URL: http://earthquake.usgs.gov/regional/world/-historical_mag_big.php; accessed 7 August 2019). However, also this list may be uncompleted.

Figures 3 and 4 confirm an increasing number of natural disasters per time interval for the last 200 years. This trend in general can be explained e.g., by a real increase of severe environmental events, by the development of new scientific methodologies and an increasing amount of scientific information, and by larger populations living in the affected regions. However, correlation analyses on the numbers and tendencies represented by the figures show that the determination

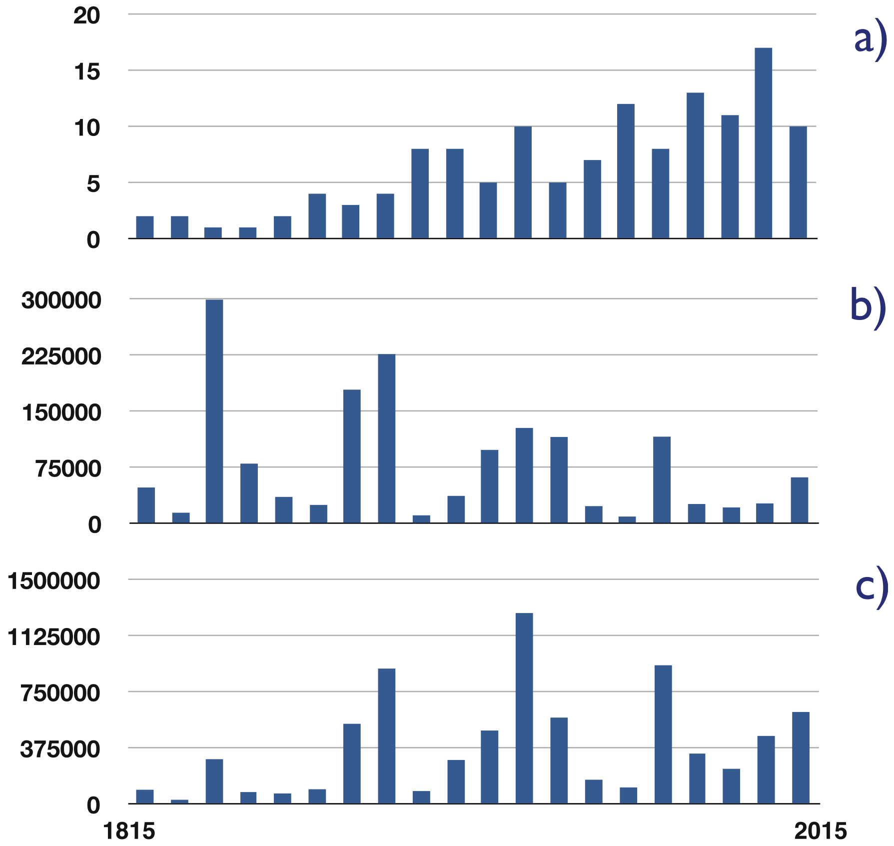

Fig. 4 No. of extreme disasters (**a**), mean no. of dead people per disaster (**b**), and sum of dead people per decennium (**c**) during the period from 1815 to 2015 (N = 133; cf. appendix). Note that the selection of disaster events might be incomplete due to the fast growing information background in this period of time (for refs. see text)

coefficients of the trendlines are small (Fig. 3, $R^2 = 0.189$; Fig. 4a, $R^2 = 0.0277$; cf. Fig. 5, $R^2 = 0.0426$).

The trends of Figs. 3 and 4b also may indicate positive effects of technologies, risk prevention such as early-warning systems, and catastrophe management including medical care. The world population increased during the last two centuries from c. one to seven billion people. Thus, the absolute and relative death toll caused by severe disasters currently does not show an increasing rate.

Figure 5 is related to the magnitude of earthquakes across the world, this graph does not show an increase of the magnitude of earthquakes over time.

The communication of danger signals from the environment might have been useful during history even if only a small proportion of forecasts became reality. Thus, natural disasters in general may be more often analysed, reflected and promoted than stories about positive tendencies, and effective risk prevention and

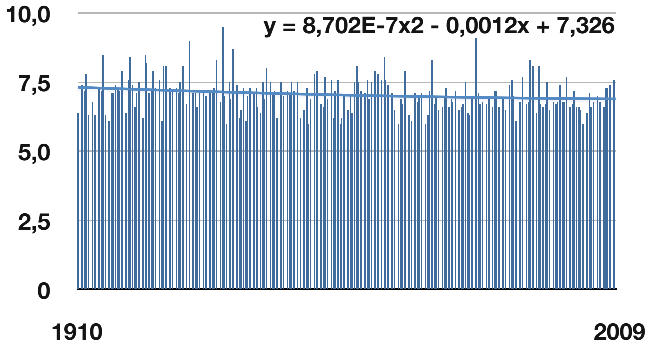

Fig. 5 Magnitude of earthquakes with a value of six or higher between 1910 and 2009 (N = 659; for refs. see text)

management during a catastrophe. Since the reports of the IPCC are focusing on change and risks the message must be alarming, or—depending on the susceptibility of the individual awareness—even apocalyptic.

These examples may indicate how our communication and awareness can be influenced by scientific information (IPCC 2014, 2018, 2019, and others).

6 Interplay of Scientific and Traditional Knowledge, Religion and Spirituality, Economy and Politics, Communication and the Media

Awareness and knowledge of the environment, including environmental risk, is the result of observation and empirical studies plus communication and interpretation of the data (Fig. 6).

The knowledge and awareness of the environment leads to consequences such as risk analysis, risk management, coast protection, rules for agriculture, forestry, fishery, aquaculture, and so on. Indeed many political decisions are influenced by the memory of disasters.

Religious consequences might also be disclaimers, fatalism or an increase in prayer or sacrificial offering. In former times, human sacrifice, cannibalism, or headhunting was used as martial consequence partially to satisfy gods or in the belief that this behaviour to avoid competition for food would be natural and normal.

Religions may answer the question of why God is creating a catastrophe, punishing humans, and how humans could improve their relationship with God and/or to nature. Since the self-conception of science is objectivity its basis is rationality, and therefore neither emotionality nor morality. Normativity and supernatural causation might be an empirical object for different scientific disciplines, but much less a conducting rational. Religion, on the contrary, is much more open for all kinds of spirituality, emotionality, fear and hope as an important part of human's

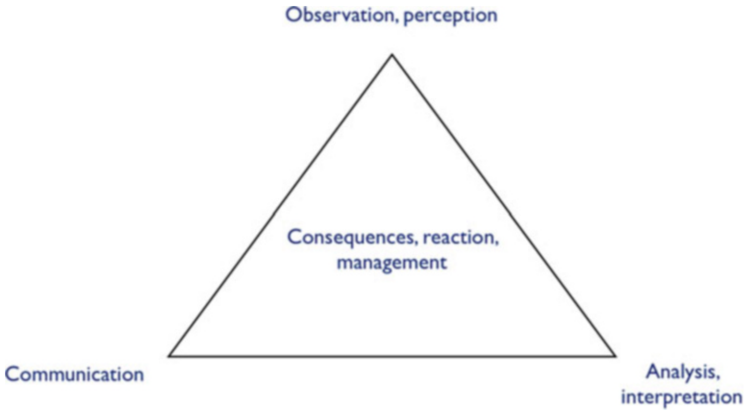

Fig. 6 From perception, analysis and communication to consequences

nature. The relationship and difference between science and religion was named the *Science-Religion Dichotomy* (Brooke 1991; Harrison 2015).

Religious beliefs traditionally treated influences on the disaster, survival through critical times, and risk management. And even if the role of religion in many parts of the world is displaced by scientific information, and even if the meaning of religion for younger people is declining almost everywhere in the world (Gallup and Lindsay 1999; Bruce 2002; Norris and Inglehart 2004) hope and prayer might become important whenever and wherever people are confronted with unexpected catastrophes or death. For many people today both are acceptable and combinable without any problem, scientific knowledge and religious belief.

Local traditional knowledge is eroding almost everywhere while the influence and availability of scientific information is increasing since the beginning of the secularization (Derman 2003; Graber and Nenova 2008; Kala 2012)—modernity vs. tradition.

Digital media enable a burst of information and communication which may be filtered by every provider and user. These filters are used according to individual interests and convictions. Moreover, new information sought normally confirms one's own values and moral systems. Science and media are not independent of awareness, investment and profit. Different scientific waves profit from political movements and public spectacles.

Fields such as disease prevention, coastal protection, or nature conservation may be related to environmental issues and are interrelated by uncountable nodes and nets. Therefore, it is still difficult to give serious prognoses and to describe reliable consequences for management.

> Of course, apocalyptic imaginaries have been around for a long time as [an] integral part of Western thought, first of Christianity and later emerging as the underbelly of fast forwarding technological modernization and its associated doomsday thinkers. However, present-day millennialism preaches an apocalypse without the premise of redemption. Saint John's biblical apocalypse, for example, found its redemption in God's infinite love. The

> proliferation of modern apocalyptic imaginaries also held up the promise of redemption: the horsemen of the apocalypse, whether riding under the name of the proletariat, technology or capitalism, could be tamed with appropriate political and social revolutions.
>
> Erik Swyngedouw (2010, 218)

7 Species Extinction and Degradation of Ecosystems

Most countries in the world have signed the CBD (Convention on Biological Diversity). There is an awesome comprising agreement to protect species from extinction and to protect ecosystems, ecosystem functions and ecosystem services around the globe. However, species extinction as the result of a process of continuous decline until the last individual has died is theoretically a sudden event, but because of an absent alarm, will rarely be recognised as such. Extinction works quietly and thus, will normally not reach the same awareness as terror, tsunamis or volcanic eruptions. Furthermore, humans can hardly feel the loss or consequences to their own lives. The same is true for many chemical components polluting water and the atmosphere, which are killing not directly but may trigger diseases that may shorten individual lives (Landrigan et al. 2017).

Environmental consciousness and relating consequences—due to science, technologies, rules—have reduced disasters for humans at different scales of space with the result of a still growing world population and increasing life span in most parts of the world. The permanent adjustment of the relationship between environment, awareness and management may still reduce the risk of direct impacts on the environment.

The growing population of humans and the increase in lifespan are used as indicators of a success story in the interplay of culture and nature (cf. e.g., de Sherbinin et al. 2007). However, environmental consciousness related to human survival/wellbeing and to biodiversity/ecosystems is different.

The political landscape for biodiversity and ecosystems is a little more complicated because environmental changes are often creeping and 'invisible'. The slowly increasing intensity in the use of land and water by a growing world population of humans, the use of wild and domestic animals, and of wild and cultivated plants during the last centuries is the most important problem for the survival of ecosystems and biodiversity. Agriculture, aquaculture, forestry, growing cities and growing infrastructure are identified as the main drivers (cf. diverse Red Lists, e.g. the IUCN Red List of threatened species). However, human health and wellbeing does not seem to be linked directly to the natural environment in these instances. Furthermore, human life and the life of other organisms seems to be decoupled.

Thus, for the protection of ecosystems and biodiversity it may be helpful to focus more on quiet than loud, on slow than fast, and on slowly increasing human activities and output than on sudden events. This might be the next step for environmental analyses. Humans would be the winners in this new paradigm since cultural life depends on natural conditions and every loss, for example of a plant species, animal species, landscape, habitat or island, is a loss of creative possibilities, survival strategies, and immaterial values such as the beauty of our surrounding.

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Appendix A

Selection of the 133 deadliest disasters (minimum death toll in brackets). E.g., broken dams, diseases, and famines are excluded. The following examples include 133 of the deadliest so-called natural disasters which happened between 1815 and 2015 (Anonymous 2008; Bradbury 2012):

1815 Volcanic eruption of Mount Tambora (92,000), 1822 Volcanic eruption Mount Galunggung (4011), 1826 Tsunami Japan (27,000), 1831 Hurricane Central America (1500), 1839 India cyclone (300,000), 1854 Great Nankaidō earthquake (80,000), 1857 Naples earthquake (11,000), 1864 Calcutta cyclone (60,000), 1868 Arica earthquake (25,674), 1868 Ecuador earthquakes (70,000), 1870 Hurricane Cuba-Florida (2000), 1871 Peshtigo Fire (1200), 1876 Great Backerganj Cyclone (200,000), 1881 Haiphong Typhoon (300,000), 1883 Erution of Krakatoa and tsunami (36,417), 1887 Volcanic eruption Cotopaxi (1000), 1887 Yellow River (Huang He) flood (900,000), 1889 Johnstown flood (2200), 1893 Chenier flood (2000), 1896 Sanriku earthquake (27,122), 1899 Hurricane Puerto Rico-Domincan Republic (3433), 1900 Hurricane Texas (8000), 1901 Eastern United States heat wave (9500), 1902 Volcanic eruption Soufriere (1680), 1902 Volcanic eruption Santa Maria (6000), 1902 Volcanic eruption Mount Pelée (30,000), 1905 Earthquake Meishan (1266), 1906 Earthquake (?) and flood Bristol Channel (2000), 1906 Earthquake San Francisco (3000), 1906 Typhoon Hong Kong (10,000), 1908 Messina earthquake (123,000), 1909 Hurricane Greater Antilles-Mexico (1500), 1911 Yangtze River flood (100,000), 1912 Volcanic eruption Kelut (5115), 1912 Cyclone China (50,000), 1916 White Friday avalanches (10,000), 1919 Volcanic eruption Mount Kelud (5000), 1920 Haiyuan earthquake (273,400), 1922 Cyclone China (60,000), 1923 Great Kantō earthquake (142,807), 1927 Gulang earthquake (40,900), 1930 Hurricane Dominican Republic (8000), 1931 China floods (1,000,000), 1932 Hurricane Cuba (3107), 1933 Tsunami Sanriku (3008), 1933 Diexi landslides (3429), 1934 Earthquake Bihar (10,700), 1935 Hurricane Carribean (2150), 1935 Quetta earthquake (60,000), 1935 Yangtze river flood (145,000), 1936 Wildfire Kursha-2 (1200), 1938 Yellow River Flood (500,000), 1939 Erzinkan earthquake (32,700), 1941 Huaraz avalanche (4000), 1942 Cyclone India (40,000), 1948 Ashgabat earthquake (110,000), 1949 Khait landslide (5000), 1952 Tsunami Borneo (4000), 1953 Netherlands-UK (2142), 1954 Hurricane Hazel (1200), 1954 Iran flood (10,000), 1954 Yangtse River flood (30,000), 1958 Typhoon Vera (5000), 1959 Typhoon Iris (2334), 1960 Typhoon Mary (1600), 1960 Earthquake and tsunami Chile-Hawaii-Philippines-Japan (2000), 1960 Cyclone Pakistan (6000), 1960 Earthquake Agadir (10,000), 1960 Earthquake Valparaiso (20,000), 1962 Huascarán avalanche (4000), 1963 Earthquake Skopje (1100), 1963 Hurricane Flora (7200), 1963 Cyclone Pakistan (22,000), 1965 Cyclone Bangladesh (30,000), 1966 Hurricane Inez (1000), 1970 Earthquake Tonghai (15,621), 1970 Ancash earthquake (70,000), 1970 Bhola cyclone (500,000), 1971 Hanoi and Red River Delta flood (100,000), 1972 Iran blizzard (4000), 1974 Hurricane Fifi (8000), 1975 Super Typhoon Nina (229,000), 1976 Earthquake Friulu (1000), 1976 Tsunami Moro Gulf (5000), 1976 Earthquake Guatemala (23,000), 1976 Tangshan earthquake (242,769), 1977 Earthquake Romania (1570), 1977 Cyclone India (20,000), 1979 Hurricane Dominican Republic-USA (2060), 1980 United States heat wave (1700), 1980 Earthquake Irpinia (2914), 1982 Volcanic eruption El Chichón (3500), 1984 Typhoon Ike (1300), 1985 Earthquake Michoacan (9500), 1985 Volcanic eruption Armero tragedy (23,000), 1986 Limnic eruption Lake Nyos (1800), 1988 United States heat wave (5000), 1988 Earthquake Spitak (25,000), 1989 Tornado Saturia (1300), 1990 Earthquake Luzon (1084), 1990 Manjil–Rudbar earthquake (40,000), 1991 Typhoon Thelma (6000), 1991 Bangladesh cyclone (138,000), 1993 Earthquake Latur (9748), 1994 Hurricane Gordon (1145), 1995 Earthquake Hanshin (6433), 1996 Cyclone Andhra (2500), 1998 Cyclone India (1000), 1998 India heat wave (2541), 1998 Tsunami Papua (3000), 1998 Hurrican Mitch (18,277), 1999 Earthquake Chi-Chi (2400), 1999 Cyclone Orissa (10,000), 1999 Avalanche Vargas tragedy (10,000), 1999 Earthquake Izmit (17,118), 2003 Bam earthquake (31,000), 2003 European heat wave (35,000), 2004 Spring flood Haiti-Dominican Republic (1605), 2004 Hurricane Jeanne (3037), 2004 Indian Ocean earthquake and tsunami (227,898), 2005 Mumbai Flood (1000), 2005 Hurricane Katrina (1836), 2005 Kashmir earthquake (87,351), 2006 Southern Leyte (1800), 2006 European heat wave (3418), 2006 Earthquake Jogyakarta (6234), 2008 Sichuan earthquake (87,587), 2008 Cyclone Nargis (138,373), 2010 Japanese heat wave (1718), 2010 Russian heat wave (56,000), 2010 Haiti earthquake (316,000), 2015 Pakistan heat wave (2000), 2015 Indian heat wave (2500).

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History of Environmental Communication and Education

Christine Börtitz and Carsten Hobohm

> *"Education is the most powerful weapon we can use to change the world."*
> *(Nelson Mandela et al. 2012, p. 101)*

> *"Education in environmental matters, for the younger generation as well as adults, giving due consideration to the underprivileged, is essential in order to broaden the basis for an enlightened opinion and responsible conduct by individuals, enterprises and communities in protecting and improving the environment in its full human dimension. It is also essential that mass media of communications avoid contributing to the deterioration of the environment, but, on the contrary, disseminate information of an educational nature on the need to protect and improve the environment in order to enable man to develop in every respect."*
> *Principle 19 of the Stockholm Declaration of the United Nations Conference on the Human Environment 1972 (United Nations 1972, p. 5).*

> *"Education can stimulate the learning process and help children and people in general to make environmentally responsible behaviour part of their everyday lives."*
> *(Gomis and Hesselink 1995, p. 29)*

Abstract Communication about nature and the environment was important throughout the history of humankind. Humans learned about their environment by observation, by leaving adverse conditions or trying to overcome unfavourable condition in the nature by practical solutions.

The exchange of information altered from *oral* to *written* and to *digital*, and from *local* to *global*. As an important result, the available amount of information simply

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exploded. However, it is reasonable to assume that especially local knowledge in many regions has disappeared.

The development of environmental education represents a chronological sequence, which in general can be subdivided in five consecutive steps:

1. Communication of disaster stories and religious narratives
   (at local scales)
2. Education in religious institutions and schools about water and food production, nature, medicine, astronomy, religion, and other disciplines with the idea to enable human life and solve social problems
   (at regional scales)
3. Scientific education of modern concepts to solve environmental problems including ecosystem services and biodiversity conservation
   (at regional to supra-national scales)
4. Transdisciplinary exchange of scientific information and education of children, students, the public and stakeholders in economy and politics with the purpose to limit environmental disaster and species extinction
   (at regional to supra-national scales)
5. Environmental education which enables avoidance of environmental catastrophes, species extinction and social disasters
   (at all spatial scales)

These phases can be seen as logical sequence of the past. However, the development in the past was not that clearly arranged as different aspects occurred at different times and in different regions independently. Today a combination of the first three steps is still globally relevant. Culturally different accentuation is realized at regional scales.

The fourth step is only partially achieved and has to be intensified. The fifth step simply has not been reached, yet. However, diverse educational programmes show a strong effort to avoid environmental disaster based on scientific knowledge across all disciplines, which are related to human wellbeing, health, survival, animal welfare, and survival of species and ecosystems.

The formal establishment of environmental education (EE) started in the middle of the twentieth century due to a worldwide growing concern about environmental problems. The concepts of environmental education and education for sustainable development (ESD) meanwhile are established in educational systems across the world.

However, also these concepts today are intermingled between short-term perspectives (health, wellbeing, profit) and long-term perspectives (survival of ecosystems and biodiversity, resource use, recycling), and between nature conservation and development. Furthermore, dependent on the concept different aspects of economy, social science, and ecology are merged with the effect that the target course sometimes is getting rather weak.

The central purpose of biodiversity conservation education (BCE) is the analysis and intermediation of the relationship between nature and culture, evolution and extinction, species and ecosystem, natural constraints and human possibilities. In general the term *biodiversity* is more related to natural sciences while *conservation* is part of the ethical-social discourse. Thus, also BCE requires the contribution of various disciplines.

Modern concepts such as EE, ESD, and BCE have to respect, disentangle and analyze extremely complex problem areas including gaps of knowledge. EE and ESD promote multiple and sometimes competing goals. Furthermore, due to the holistic approach, the targets of ESD are partially ambiguous, while BCE is related to smaller and clearer targets.

Since many environment-related education approaches are interdisciplinary if not holistic, school curricula of traditional core disciplines often do not provide enough space for relating contributions.

Independent of the different positions and phases, the enlargement and intensification of environmental education in public schools and media is seen as an important measure parallel to political decisions and practical management of ecosystems.

Keywords Environmental education (EE) · Education for sustainable development (ESD) · Biodiversity conservation education (BCE)

1 Introduction

Environmental education (EE) is a modern concept, which emerged in the twentieth century. William Stapp (1969, 31) provided one of the first definitions:

> Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution.

In the following decades, many international conferences developed this concept even further and created a basis for integrating EE, and later for education for sustainable development (ESD). General ideas have been dispersed not only in the world's educational systems but also in the everyday life of people. To reach the public, conference communication via mass media is seen as an essential part (e.g. United Nations 1972; UNEP and UNESCO 1978; IUCN, UNEP, WWF 1980), because "[a]n *information campaign can make individuals aware of their responsibility for the environment*" (Gomis and Hesselink 1995, p. 29).

Environmental education (EE) and education for sustainable development (ESD) are relatively modern concepts. This contribution aims to offer an overview about historical relationships between nature, knowledge of environmental processes, culture and environmental communication and education. Cultural episodes from different epochs may be interpreted as stepping stones to the development of modern communication and education about the environment. The examples deal with topics like, inter alia, nature, astronomy, medicine, hygiene, and waste management.

It can be assumed that people observed their surroundings, thought about nature, communicated about benefits and danger from nature and reflected their own reaction at all times. It was important to know which natural products could be used and which animals could be hunted. Like humans today prehistoric people had to accept their dependence on nature, and therefore feared, adored, restored, and used nature for wellbeing and survival. Moreover, it can be assumed that they were discussing ideas and convictions and shared disaster stories with old and young people and tried to enhance their knowledge, education and behaviour.

2 Education and Communication: Examples of Teaching and Learning About Nature During the Past and Present

Communication about nature may be an anthropological constant. Cave paintings from the Ice Age document environmental observations most likely used for ritual ceremonies. Although the interpretation is difficult (Breidbach 2015) the paintings might be interpreted as part of the environmental communication and self-reflection.

Shamans accompanied the community with ceremonies during every intervention in the environment, from planting to harvesting, hunting, birth and death. This proved to be effective as it led to a stabilisation of the social life (Breidbach 2015).

For the Hopi of Arizona it was important to coordinate one's own actions with the life cycle of nature since humans were seen as part of nature. According to their narratives, opposing against nature would lead to a destruction of the world (Breidbach 2015).

Today education for environment-friendly behaviour should be integrated in formal and non-formal education. Furthermore, self-education using mass media and the internet is possible everywhere and at any time.

In the following, different examples of education in different parts of the world may indicate phases of communication and education on nature and the environment.

2.1 Ancient Egypt and the Cultural Meaning of the Nile

The availability of water has always been an important factor for the establishment and prospering of cultures. In Egypt, the lowland Nile, an enormously water-rich floodplain, has determined the cycle of life in its surroundings since ancient times and defined and still defines the life in a hostile environment. Regular floods fertilize the river valley with nutrient-rich sediment, guaranteeing an enormous fertility of the land. Even in the days of the pharaohs, Egyptians already knew about the importance of the Nile for their prospering culture. Therefore, they combined agriculture with celestial constellations. The star Sirius and the occurrence of the Nile floods marked the beginning of the year. By observation, they knew that the Nile would bring enough water for irrigation when Sirius rises shortly before sunrise (Breidbach 2015; Prell 2009; Ward 1992). Since the floods did not reach the optimal level for inundation every year the Egyptian culture was always sensitive to droughts. Therefore, irrigation systems were established using canals and dykes extending from the riverbank to the edges of the desert (Antoine 2017; Endesfelder 1979). Even in good years with high floods, all parts of the valley could only be reached by irrigation via canals (Radkau 2000). The fertilization of the land surrounding the Nile was a premise for the establishment of a flourishing agriculture along its riverbed (Breidbach 2015; Endesfelder 1979). The pace of the Nile, including the inundation, set the pace for the ancient Egyptian culture. It tied the country into a seasonal rhythm and determined the order of life including annual, daily, cultural, and cult life.

2.2 Sumerian Culture

Mesopotamia, located between the rivers Euphrates and Tigris, was a fertile region. This rich agrarian landscape, however, only produced sufficient yields through intensive farming and irrigation (Breidbach 2015; Radkau 2000). The Sumerians recorded observed phenomena in written documents, which were collected in archives or libraries. These collections included, among other things, knowledge about mathematics, cosmology, natural history and medicine. Especially medicinal knowledge can be found in such documents. For example, more than 250 medicinal plants, 120 minerals and over 100 animal products were used as remedies. Furthermore, models of organs of sacrificial animals made of clay were used. These models served as a kind of database for operating priests, displaying the special features also of insights of animals (Breidbach 2015).

2.3 Chaco Canyon Culture: Environment and the Influence of Astronomy

The following description of the achievements of the Chaco Canyon Culture implicates an outstanding knowledge especially about astronomy and technological construction, as well as inventiveness in dealing with partly self-inflicted environmental problems, which they orally shared with several following generations (Sofaer 1997). It also shows how overexploitation and unsustainable use of the environment aggravated by unfavourable environmental conditions lead to degradation and uninhabitability of entire regions. While making an effort to survive in a region as long as possible people learn from and communicate about nature. However, as long as the underlying causes of the occurring environmental problems are not identified and eliminated, there is no way of change and improvement—a realization which is still valid today.

The Chaco Canyon Culture lived in the area of a valley in the catchment area of the upper San Juan River in the state of New Mexico, which was the ritual centre of a large system of Chacoan communities (Mills 2002; Pauketat and Emerson 2007; Sofaer 1997; van Dyke 2004). Construction of extensive roads and the Chaco pueblos, great houses, started approximately 900 AD and finished at about 1130 AD, the presumed end of inhabitation of Chaco Canyon (Dean 2001; Mills 2002; Pauketat and Emerson 2007; Sofaer 1997).

When building the first great houses, the surroundings of Chaco Canyon consisted of pinyon-juniper woodland and ponderosa pine forests. The timber of the woodlands was used for architecture and fuel until these resources were fully exploited. Around the 910s, deforestation already exceeded the natural regeneration rate (Betancourt and van Devender 1981; Dean 2001). On this account, the Chaco Canyon culture established an elaborate road system to obtain resources from outlying communities and mountain slopes (Betancourt and van Devender 1981). The situation aggravated due to a semiarid climate, low precipitations, short growing seasons, several droughts and unfavourable soil conditions such as high salinity and pH (Benson et al. 2006; Dean 2001; Schlanger and Wilshusen 1996). In trying to overcome these environmental conditions and to conduct agriculture, water control features were established (Benson et al. 2006; Mills 2002). Precipitation, seasonal runoffs and water from the ephemeral Chaco River were used for agriculture (Benson et al. 2006; Schreiber 1997; Vivian 2001). “Elaborate water collection and distribution systems” (Dean 2001, p. 35) as well as different methods of farming with runoffs and floodwater were used, e.g. canals, gridded gardens, terraces, ditches and dams (Benson et al. 2006; Mills 2002; Schreiber 1997; Vivian 2001).

To obtain resources from outside the canyon and to connect with outlying communities, an elaborated road system was built (Betancourt and van Devender 1981; Schreiber 1997). Next to this economic function, Chacoan roads had a symbolic meaning as ritual pathways and for cosmology, connecting structures and leading directly to prominent landforms or natural features such as springs, lakes, and pinnacles (Marshall 1997; Mills 2002). Of particular importance were the four cardinal directions completed by the vertical directions up and down, representing the physical, social, spiritual, upper and lower worlds (van Dyke 2004), as well as the directions of solar und lunar cycles (Sofaer 1997). Especially the north-south meridian, expressed through the Great North Road and the Great South Road, the two longest road segments, seemed to be important axes. From Chaco Canyon both roads extend over about 50 km in each direction and terminate at sacred places—the northern road at Kutz Canyon and the southern one near Hosta Butte (Marshall 1997; Sofaer 1997). Not only roads, but the entire architecture of Chaco Canyon expresses the archaeoastronomical alignments of the Chaco Canyon culture (Farmer 2003; Pauketat and Emerson 2007; Sofaer 1997; van Dyke 2004). Astronomy was the determining factor for the placement and internal construction of the great houses as well as the road system (Sofaer 1997; Stein et al. 1997). Building walls were aligned according to astronomical events (e.g. Pueblo Alto, Pueblo Bonito) (Farmer 2003; Marshall 1997; Sofaer 1997). The internal geometry of major buildings corresponds to solar and lunar cycles, petroglyphs record solstices, equinoxes and lunar standstills (e.g. the Sun Dagger on Fajada Butte) (Farmer 2003; Sofaer 1997).

Not only depleting resources in the surroundings influenced the culture and, in the end, the abandonment of Chaco Canyon, but a combination of several factors (Dean 2001). Well documented are unfortunate changes of environmental conditions in the twelfth century (Mills 2002). Multidecadal droughts occurred around 1130 AD as well as 1250 AD (Benson et al. 2006; Dean 2001). Erosion, as a result of deforestation, probably destroyed much of the arable land (Betancourt and van Devender 1981). Field salinization, due to the predominant use of Chaco River water for irrigation instead of less saline runoff water (Vivian 2001), aggravated the situation. In addition, the incising Chaco River lowered the water level below field level and reduced the already small amount of water available for irrigation (Benson et al. 2006; Schlanger and Wilshusen 1996). Finally, the Chaco Canyon culture was not able to survive in the region under these environmental conditions.

2.4 Education Systems of the Ancient Greece, Alexandria and Roman Empire

In Antiquity, philosophers and scholars tried to understand their world by studying and observing nature and by discussing their insights and interpretations with other scholars and their students. They discussed observations and exchanged ideas and experiences. A new way of scientific thinking developed. Ideas and concepts were formulated, reviewed and accepted or rejected. This laid the fundament of European science (Breidbach 2015). During this time philosophy was the leading discipline, and included topics such as astronomy, climatology, natural history, plant and animal sciences, geography and others. Knowledge was mainly transferred orally, e.g. in philosophical schools. The general education consisted of several consecutive schools. Most students attended the *school of letters* to learn reading and writing. Afterwards, a person could continue with a more specialized study at the *school of the grammarian*, followed by the *school of rhetoric*. For final education a person attended the *school of the philosopher*. Education at the last two schools was expensive. Therefore, only a few could afford attending (Watts 2006). The central educational institutions of the ancient world taught the entire science programme. Centres were the Mouseion with attached library in Alexandria, as well as Plato's Academy and Aristotle's Lyceum in Athens. Other large and important schools of philosophy existed for example in Ionia and Constantinople (Vinzent 2000). Another possibility for education was the Gymnasion in Greece.

Alexandria was famous for its central educational and research institutions, the Royal Library and the Mouseion. Both institutions already existed in the first century BC. During flourishing times, the library contained about 400,000–500,000 papyrus rolls. After being repeatedly damaged by fires, the Arabs, who conquered

Alexandria, destroyed the remaining documents of the library as well as the Mouseion in 642 AD (Breidbach 2015). Thereby much knowledge was irretrievably lost.

The Mouseion was the institution, where poets, oretors and students of grammar studied. It was a place to worship the muses with celebrations, as well as with instructions and lectures. The basis for this was the library (Vinzent 2000). Scholars researched and discussed their ideas, especially in disciplines such as astronomy, geography, mathematics, but also botany and zoology, astronomy, astrology, optics, literature, grammar and geography. Research findings were documented on scrolls and copied in scriptoria for the distribution to libraries, scholars and private persons. In addition, knowledge was transferred through discussions in schools and public places (Breidbach 2015). A vivid philosophical study and teaching life existed (Vinzent 2000). This approach and academic life were similar in Alexandria and in Greece.

This example shows, that education, intellectual live and research had several centres throughout the world leading to an exchange of ideas and experiences across borders. Therefore, it is not surprising that a network of colleagues and students existed between Alexandria and important Greek teaching centres, especially Athens, as well as a high mobility between academics (Vinzent 2000; Watts 2006).

The Greek culture during antiquity is one important root for today's science. Therefore, the most important philosophy schools as well as gymnasia as places of advanced education in Greece will be presented exemplarily. However, other places for intellectual education existed as well. For example, it was common that young people of noble origin were educated by house teachers which were usually slaves or freed persons (Kah and Scholz 2007). Scholars with broad knowledge about philosophy founded philosophy schools. Objectives of the schools were teaching students, conducting discussions and debates and securing knowledge by writing it down. Many philosophy schools existed, for example the School of Miletus, the School of Pythagoras (the Pythagoreans) or the School of Elea. These philosophy schools were accessible only for privileged people who were financially secure and had time to spare—the upper class, the social elites (Breidbach 2015). The most famous philosophy schools in Athens were the Platonic Academy and the Aristotelian Lykeion. Both were private foundations and lived from the support of their members and patrons, both were educational and teaching institutions, and both formed the tradition of learning and teaching (Breidbach 2015).

Plato (427–347 BC) belonged to the social elite of Athens by birth. His education included instructions in grammar, music and gymnastics, all according to his social position. Later on, he was a student of the philosopher Socrates. Plato founded his own philosophical school, the Academy, in Athens a few years after the death of Socrates. There he taught his philosophy, which later on became the scientific concept of the occident. Knowledge is based on establishing a context in finding rules and observing boundary conditions (Breidbach 2015). Aristotle (384–322 BC) came from a family of physicians. It is assumed that he, like Plato, received an education according to his social position. He then joined Plato's academy and remained a member until Plato's death. Before he founded his own school, the

Lykeion, in Athens in 355 BC, he taught the later Alexander the Great, son of King Philip II of Macedonia. Aristoteles' works show what Greek philosophers knew and thought about natural sciences. He summed up the entire knowledge of his time about nature and integrated his own observations and evaluations (Breidbach 2015; Mägdefrau 1992). Inter alia, Aristotle wrote the "Historia animalium", in which he developed the first systematic of the animal kingdom. This system remained valid until modern times. One of his students, Theophrastus (371–287 BC), carried out basic botanical research, researching the plant itself and its benefits for agriculture and medicine (Flad-Schnorrenberg 1978).

The Gymnasion (gymnasium) was the central institution for education of Greek knowledge and culture. It was a spacious complex of multifunctional buildings with walkways, sport complexes and a park in which a wide range of teaching and instruction was offered. Sometimes an archive, a library and in some cases thermal baths were included (Breidbach 2015; Kah and Scholz 2007). The Gymnasion was no state educational institution of modern character providing public teaching staff and general curricula. It was an institution of general education and urban leisure for young and adult. The access was restricted to sons of free Greek citizens between the ages 7 and 30, if the father could afford the attendance fee. Consequently, it was only accessible for people of the upper class. The Gymnasion provided elementary and intellectual education such as cultural techniques of reading, writing and arithmetic, arts and crafts, rhetoric and philosophy, body hygiene and physical education as well as instruction in war crafts and military training. Lectures and courses by scholars and lectures about local cults and ceremonies were also part of the education programmes (Kah and Scholz 2007).

In the Roman Empire, no explicit educational centres existed. In households of higher social position house slaves, mostly enslaved Greek scholars, taught children reading and writing. The Roman youth was trained by the military, not at grammar schools or academies. In addition to the military training, educated Romans often went on study trips to Greece or Asia Minor. Thus, education and training were more practice- than theory/philosophy-oriented. Philosophers were rather insignificant. Knowledge of that time was handed down in architecture and less in writings (Breidbach 2015; Sonnabend 2006). One example is the Roman water system. To improve health conditions public health facilities, like latrines and public baths, were accessible even for the poorest citizens. Romans observed that surface water could be used for many activities, like flushing latrines. By contrast, the higher quality of spring water makes it more suitable for human consumption. "Inventors of the first integrated water service, the Romans managed the water cycle from collection to disposal, providing dual networks to collect spring water and dispose of storm and wastewater" (Lofrano and Brown 2010, p. 5257). Prior to the construction of aqueducts, Romans built sewers. For example, the Cloaca Maxima already existed in the sixth century BC. The first aqueduct, the Aqua Appia, was only built in 312 BC (Lofrano and Brown 2010). At the end, 11 aqueducts carried water to Rome (Sonnabend 2006). Nature was dominated and handled practically. Another example are Roman transport routes, which were chosen for practical reasons. This required a complex knowledge about nature, inter alia, distances, regional climates and their seasonal chances. It implicates a comprehensive education and knowledge sharing about nature. For example, they preferred the Atlantic route for transportation from Baetica, southern Spain, to a military base on the Rhine, even if the travel distance was much longer than the direct connection. The Atlantic route was the only continuous waterway whereas transportation via land required several instances of transhipping. Thus, the transport along the coast was often much faster than on land. In addition, ships hold greater loads than river barges. Therefore, transportation costs were much cheaper (Schäfer 2016). This example shows that education about the environment was also of economic interest in the past.

The task of a Roman scholar was to collect and preserve the discoveries of the past and to make it understandable for the Roman audience. Therefore, there were many specialised journals and books on e.g. agriculture, fruit growing and cattle breeding. In contrast to Greek knowledge collections, these writings hardly contained any own observations (Flad-Schnorrenberg 1978). One example of a Roman scholar is Marcus Porcius Cato Censorius (234–149 BC), a politician, former military and landowner of a farm near Rome. He wrote "De agricultura", a handbook for landowners and a guide to an efficient and profit-oriented farm management. Content of this book are, for example, location of the farm, land use, viticulture, cultivation of olives, field crop cultivation, cattle breeding, and administration (Breidbach 2015; Sonnabend 2006).

A contemporary scientific writer of the Roman Empire was Caius Plinius Secundus Maior (79–23 BC). He descended from a civil servant family and worked as a politician and later on as a fleet commander. In the "Naturalis historiae libri XXXVII", a comprehensive natural history in 37 volumes, he created a sort of meta-analysis of knowledge of all authors known to him. This natural history covers topics such as astronomy, geography, humans, animals, plants, drugs, and minerals. These volumes were the main source of natural history instructions for one and a half millennia. Plinius died during the eruption of Vesuvius while he wanted to make observations on earthquakes and the eruption (Breidbach 2015; Mägdefrau 1992).

2.5 Middle Ages, Water, Epidemics and Medicine

During the Middle Ages, nature in Central Europe was regarded as something inferior, possessed by evil spirits. God was located outside and had to control diabolical attitudes of humans and nature.

Due to the population growth the need for food, wood and arable land increased enormously and led to overexploitation and damage of forests and soils (Schubert 1996). In addition, due to the foundation and expansion of cities and the increasing pressure to landscapes by intensification of agriculture productivity, citizens changed the rural and urban environment immensely. The intensive use of landscapes expanded from lowlands and lower mountain belts to higher elevations in mountain regions. As a result, huge amounts of soils were washed out and transported from devastated mountains to the lowlands where they destroyed large parts of farmland in the floodplains (Fumagalli 1992).

In northern Germany open sand dunes originated and expanded (Schubert 1996). Devastated landscapes, natural disasters and a growing population resulted in epidemics and famines (Dirlmeier 1996). People had to realize that the transformation of natural conditions and maximal exploitation is one possibility but to mitigate its negative influences they had to seek out technological solutions. The overexploitation forced the beginning of forest protection.

First reforestation projects were initiated by monasteries. Forests were protected for various reasons, inter alia for hunting, woodland pastoralism and limited timber production. From the fourteenth century onwards, cities prevented overexploitation of their urban forests via protection measures due to their dependence on wood. Measures were, inter alia, the restricted use of commons and reforestation (Fumagalli 1992; Schubert 1996).

At the end of the Middle Ages, cities normally had a public school where cleric men taught. However, there was not much left of the ancient education, due to the decreasing knowledge of the Greek and Latin languages as well as catastrophes and accidents which destroyed many ancient writings irretrievably. Much knowledge was lost. In the year 800 AD, Charles the Great carried out an educational reform with the aim to raise the educational standard. In order to achieve this, the basic training of priests was improved and bishops' schools were founded. Monastery schools and priest education were organized at three levels:

1. elementary knowledge including reading, writing, singing, mathematics, calendar studies,
2. the "septem artes liberals" including grammar, rhetoric, dialectics, arithmetic, geometry, astronomy, music,
3. and the priestly vocational training including reading and interpreting of holy scriptures, sermon, divine service, teaching of the doctrine of faith (Piltz 1982).

During the second half of the Middle Ages, after 1100, secularization took more and more place. Students stated to ask rational questions and tried to get more convincing answers. However, cleric men still taught in schools and universities (Piltz 1982; Röckelein 2015). These cleric men were at the same time clergyman and scholars, even thou they did not necessarily belonged to the monks and priests (Le Goff 1994).

During the eleventh century, first universities were founded, even if the name university was established not before the fifteenth century. Until then it was called "stúdium generále" (Piltz 1982). The oldest universities are Paris, Oxford and Bologna (Heidelberger 1985). The Arts Faculty curriculum in Paris included subjects such as philosophy of antiquity, rhetoric, grammar, quadrivium, and ethics. However, the natural philosophy and the metaphysics of Aristotle were prohibited. This was a peculiarity of Paris, existing only until 1366. Toulouse and Oxford, which competed with Paris as sites of philosophical scholarship, were not affected by the ban (Piltz 1982). Four faculties were established: Liberal Arts, Law, Medicine, and Theology. Next to being colleges, the medieval universities partly included primary and secondary school education. Books became the basis of teaching (Le Goff 1994).

With the end of the Roman Empire, the standards in health and sanitary changed and the meaning of water was interpreted differently. People in the Middle Ages considered water as unhealthy (Lofrano and Brown 2010). Focusing on economic strength and impressive municipal buildings, like cathedrals, instead of public and personal health caused two main problems for medieval towns: drinking water supply and waste disposal. Both resulted in enormous problems for health. Usually people disposed of waste by throwing it out in the street (Ewert 2007; Lofrano and Brown 2010). In addition, much waste was disposed into streams and rivers, like animal carcasses and waste of artisans. People used inner-city groundwater and spring water via public and in-house wells. Very often, the consequences were infectious diseases and epidemics such as plague, smallpox or cholera, which claimed millions of victims (Dirlmeier 1996). "People in the Middle Ages not only were aware of the detrimental impact their way of life had on the physical environment and on civic life, they also found solutions to this challenge, although some of the institutional arrangements may not have been completely efficient" (Ewert 2007, p. 247). In the course of the Middle Ages municipalities developed several means to deal with these sanitary problems. Solutions were, inter alia, building sewers, which were cleaned and maintained by the communities, and the implementation of public baths (Ewert 2007).

The expansion of epidemics such as the Black Death (*Yersinia pestis*) and leprosy (*Mycobacterium leprae*) was a consequence of increasing populations in cities and the demarcation of traditional habitats, while the lives of most people were still within a narrow geographical range. In the end, control and containment was a merit of human precautions (Radkau 2000). "Leprosy was widespread, but it did not affect many in any given community" (Browne 1975, p. 490). The medicine of this time could not eliminate the disease but due to excellent observations, medics could detect the disease in its variable forms and infected people were isolated. Since the thirteenth century, the disease has been repressed due to the separation of those affected by infectious forms of leprosy, the reduction in the size of households and the raising of socio-economic standards (Browne 1975; Keil 1996). The Black Death spread in the middle of the fourteenth century probably from Central Asia throughout Europa, occurring in several cycles (Keil 1996; Perry and Fetherston 1997). Due to a much more virulent pathogen than leprosy, consequences were much more devastating, killing approximately 30–40% of the European population. The reason for the decline of the plague is unclear. Various theories, including rodent populations and *Y. pestis* itself, are all partially flawed. This epidemic resulted in great changes especially in the medical system, its education and practice. "These included the advent of clinical research, inclusion of surgeons and surgery in medical education, public health regulations [. . .], and the development of hospitals that attempted to cure patients, not just isolate them" (Perry and Fetherston 1997, p. 36).

In the Middle Ages, not only scientific knowledge of antiquity but also much of its medical knowledge was lost. Therefore, medicine consisted of intuition and traditional healing arts (Piltz 1982). The contribution of monks and nuns was very high during this time, since medicine rested mostly in their hands. They kept monastery gardens with herbal plants, among others, and helped at sickbeds. They also transcribed and thus preserved and disseminated the few survived Greek and Roman medical writings with added changes and omissions of some details (Köpp 1980). During the twelfth century, medicine became an academic discipline and thus one of the four sciences. The medicinal education consisted of verbal advice and experience, the use of medical methods from classical Greece and knowledge from Arabian medicine. Didactic graphics, like the "Wundermann", a Catalogue of medical theories for the treatment of infirmities, were used. Doctor candidates had to have a high general education and knowledge of the ethical medical rules of the Hippocratic tradition. The impact on public health was high. The interest in general hygiene increased which partly explains why leprosy declined in the fifteenth century in Europe (Piltz 1982).

2.6 Early Modern Times: Development of Natural Sciences

The Early Modern Age was an epoch with many changes and great discoveries. Nicolaus Copernicus discovered that the earth circles around the sun. Columbus discovered America and Fernão de Magalhães was the first to circumnavigate the world. With the expedition on the Beagle, Charles Darwin laid the foundation for his evolutionary ideas about the origin of the species. Marco Polo, Carl von Linné, Alexander von Humboldt, Jean Leopold Nicolas Frederic Cuvier and many others explored the world using a different and rational understanding of natural sciences. Whereas in the Middle Ages the natural sciences served to support theology, they gradually emancipated from the authority of the Church in early modern times. Science was supposed to be understandable and accessible for everyone, without the participation of the church. Scholars withdrew from the Church's authority by pursuing their research activities in non-university fields. Therefore, the actual scientific research and thus the practical application of sciences did not take place at the universities but in private circles, in workshops of artisans, at academies and princely courts, in private associations, etc. Scientific institutions like the Académie des Sciences and the Royal Society made new research internationally known (Thiessen 1985; Varchmin 1985). The publications of scientific journals by these societies reached the entire educated public (Kearney 1971). In addition, during the sixteenth and seventeenth century there was a change of how to approach research. Sometimes this is referred to the revolution of the natural sciences. Starting from the unquestioned belief in natural conditions of traditional authorities, scholars changed their approach in developing and testing of preconceptions. The application of hypotheses, mathematical models and experiments in all fields became a common procedure (Kearney 1971).

In 1660, the Royal Society of London for the Improvement of Natural Knowledge was founded under the patronage of King Charles II (Crosland 1992; Purver 1967). Via the Journal of the Royal Society, the Philosophical Transactions, and an extensive correspondence network, knowledge was distributed and discussed (Rusnock 1999). The Royal Society took its philosophy from Francis Bacon. Natural sciences arose through cooperation between researchers. Science was an instrument to understand and influence the conditions on earth. The purpose was to control the nature for the benefit of humans (Heidelberger 1985). Thus, the focus was utility and practical knowledge (Purver 1967), to improve the technical efficiency of individual industries and to create technical and practical inventions. Therefore, it is not surprising that industrialisation started in England (Kearney 1971). During the eighteenth century, "the Society developed as a legitimating body—a sort of review board—for scientific reports" (Rusnock 1999, p. 156).

In 1666, 6 years after the foundation of the Royal Society, King Louis XIV founded the Académie des Sciences in Paris, a state institution. The state invested not only in research but also paid salaries for the members of the institution. The focus of this society was a very different one than that of the Royal Society. Scholars could satisfy their intellectual curiosity. Thus, scholars researched in the six main scientific subjects recognized in the eighteenth century: mathematics, physics, mechanics, astronomy, chemistry, botany and anatomy (Crosland 1992; Hahn 1971). However, if they wanted to share their knowledge, each article had to get the approval of the Academy before being published in the Academy's Journal des Savants (Hahn 1971).

Still, until the nineteenth century, there was no natural science faculty at the universities. Scientific knowledge belonged to the general knowledge of every student. It had to be acquired as part of the basic studies (bachelor's degree) and the subsequent philosophy study (master's degree). Only after that, a student began his actual specialist studies: theology, legal studies or medicine (Thiessen 1985).

2.7 The Roots of Modern Environmental Education

During the nineteenth century, several environment related movements developed worldwide, like the conservation movement, the environmental movement, outdoor education and nature study. Harvey (1976) already mentioned that the environmental movements probably comprised different groups, individuals and interests, which only superficially integrated same ideas. This statement can probably be applied to each of the movements. Still the terms education and environment were not brought together until the mid-1960s.

Psychological, philosophical, and ecological/biogeographical roots of these movements, as well as of environmental education (EE), can be traced back to the eighteenth century. Palmer (1998) states that the development of EE was significantly influenced by "some of the 'great' eighteenth- and nineteenth-century thinkers, writers and educators, notably Goethe, Rousseau, Humboldt, Haeckel, Froebel, Dewey and Montessori" (Palmer 1998, p. 4). These authors started to spur concern about the environment as well as environmental problems. They raised the reader's awareness and knowledge about nature and environment and focused their attention on the man-nature relationship. “Man and Nature or, Physical Geography as Modified by Human Action” by George Perkins Marsh (1801–1882), “Nature” by Ralf Waldo Emerson (1803–1882), “Walden” by Henry David Thoreau (1817–1862), founding father of the US-American nature conservation movement John Muir (1838–1914), and “A Sand County Almanac” by Aldo Leopold (1887–1948) are to be named. In addition, Jean Jacques Rousseau (1712–1778), Sir Patrick Geddes (1854–1933) and John Dewey (1859–1952) influenced the field of EE. They encouraged not only to memorize facts about science but also to discover them, to learn by doing, by experiment and by direct contact (Harvey 1976; Monroe and Krasny 2013). “The writings of these thinkers greatly shaped EE by influencing its early predecessors” (Monroe and Krasny 2013, p. 11).

2.8 Current Concepts of Environmental Education

The twentieth century was characterized by a growing environmental awareness and the need for its protection due to growing environmental problems worldwide. In the U.S., for example, erosion, water quality problems and dust storms characterized the 1930s, caused by a combination of dry farming techniques, economic depression and droughts due to high temperature and rainfall deficits. The consequences were devastating effects on agriculture (Biedenweg et al. 2013; Lee and Gill 2015; Schubert et al. 2004). This environmental catastrophe gave rise to a conservation education movement with the goal to create an awareness of environmental problems and the significance of environmental conservation (Disinger and Monroe 1994).

As consequences of industrialization and mechanization in times of economic miracles, as well as the exponentially increase in world population and improved communication around the world after World War II, people started to become sensitive to global environmental problems such as tanker accidents, dying forests and the greenhouse effect (Disinger and Monroe 1994; Li and Zbicinski 2014). People got the impression of resource scarcity accompanied with an increase of environmental disasters. Social movements started to protest against growing environmental problems caused by the economy. In 1962 Rachel Carson published “Silent Spring”. This book describes, inter alia, the results of savage usage of pesticides on ecosystems (Carson 1962). It triggered political debates, which resulted in the prohibition of DDT (Pufé 2012). Afterwards “[c]alls for education dealing with the environment became increasingly more persistent” (Disinger and Monroe 1994, p. 11).

Due to the orientation of educational programmes on basic resources, William Stapp identified the need to change this approach to an education including man and environment. He developed and published one of the first definitions of ‘environmental education’. “Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (Stapp 1969, p. 31).

"The Limits to Growth", published in 1972 by the Club of Rome, got worldwide awareness. The survey draws a gloomy picture of the future of the planet if the major problems (world population growth, food production, capital growth and industrialization, resource consumption and environmental pollution) were not immediately dealt with to achieve a state of equilibrium necessary for the survival of humanity. This book increased the awareness that earth is a finite and closed system of interconnected factors, and that human overuse through waste and overexploitation threatens not only the actual economic wellbeing but also the livelihoods of future generations and the existence of the whole humanity (Meadows and Donella 1972).

The ensuing global social and environmental movements, assisted by the publication of the Club of Rome and the recognition of an increase of environmental problems, led to a large number of conferences until today (Table 1).

One of the first international conferences related to the environment was the United Nations Conference on the Human Environment in Stockholm 1972. This conference linked environmental issues with social developments in industrialised and developing countries. One of the principal topics was EE (principle 19, recommendations 96 and 97). Environmental education should be integrated not only into the entire school education but also into public education via lifelong learning. The approach should be interdisciplinary. The goal is for people to create an awareness of environmental issues, and to get the public to actively participate. To reach this, people are to be educated to take the steps within their own means in order to control and manage their environment (United Nations 1972).

The Stockholm Conference was the catalyst for the UNESCO/UNEP International Environmental Education Program (IEEP), launched in Belgrade in 1975. The ratified Belgrade Charta defines the objectives of EE: awareness, knowledge, attitude, skills, evaluation ability and participation. In addition, a comprehensive list of guiding principles on environmental education, including lifelong learning and the responsibility to future generations, was integrated. According to Li and Zbicinski (2014) this charter proposes the most widely accepted definition of EE. "The goal of environmental education is: To develop a world population that is aware of, and concerned about, the environment and its associated problems, and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems, and the prevention of new ones" (UNESCO and UNEP 1975, p. 3).

At the following Intergovernmental Conference on Environmental Education in Tbilisi in 1977, the definition of environmental education was extended. "Environmental education is an integral part of the education process. It should be centred on practical problems and be of an interdisciplinary character. It should aim at building up a sense of values, contribute to public well-being and concern itself with the survival of the human species. Its force should reside mainly in the initiative of the learners and their involvement in action and it should be guided by both immediate and future subjects of concern" (UNEP and UNESCO 1978, p. 19).

Table 1 Important conferences, workshops and prominent publications of the twentieth century concerning environmental education (IUCN, UNEP, WWF 1980; UNEP and UNESCO 1978; UNESCO 1990, 1993, 1997, 2000, 2005; UNESCO and Federal Ministry of Education and Research of Germany 2009; UNESCO and UNEP 1975, 1987, 2007, 2012; United Nations 1972, 1992a, b, 2002, 2012, 2015; WCED 1987)

Year	Origin	Conference	Documents
1972	Stockholm/ Sweden	United Nations Conference on the Human Environment	Report of the United Nations Conference on the Human Environment
1975	Belgrade/ Yugoslavia	International Workshop on Environmental Education	The Belgrade Charta: A Framework for Environmental Education
1977	Tbilisi/Georgia	Intergovernmental Conference on Environmental Education	Final Report
1980			World Conservation Strategy
1987	Moscow/Russia	Congress on Environmental Education and Training: Tbilisi Plus Ten Conference	International Strategy for Action
1987	Norway		Our Common Future: Brundtland Report
1992	Rio de Janeiro/ Brazil	United Nations Conference on Environment and Development: The Earth Summit	Agenda 21, Convention on Biological Diversity
1997	Thessaloniki/ Greece	International Conference Environment and Society: Education and Public Awareness for Sustainability	Declaration of Thessaloniki
2005–2014	Decade of Education for Sustainable Development		
2007	Ahmedabad/India	International Conference on Environmental Education	Ahmedabad Declaration
2009	Bonn/Germany	UNESCO World Conference on Education for Sustainable Development	Bonn Declaration
2012	Rio de Janeiro/ Brazil	United Nations Conference on Sustainable Development: Rio +20	The Future We Want
2012	Tbilisi/Georgia	Intergovernmental Conference on Environmental Education for Sustainable Development: Tbilisi +35	Tbilisi Communiqué
2015			United Nations, Transforming our world: the 2030 Agenda for Sustainable Development

41 recommendations should help the integration of EE into national and international policy, into formal and non-formal education and into curricula of schools.

The Tbilisi Plus Ten Conference of 1987 proposes a new definition of EE: "Environmental education (EE) is regarded as a permanent process in which individuals and the community gain awareness of their environment and acquire the knowledge, values, skills, experience, and also the determination which will enable them to act—individually and collectively—to solve present and future environmental problems" (UNESCO and UNEP 1987, p. 11).

In 1992, the Earth Summit took place in Rio de Janeiro. Five Rio agreements were discussed and adopted: the Rio Declaration on Environment and Development, Agenda 21, the Statement of Forest Principles, the United Nations Framework Convention on Climate Change and the United Nations Convention on Biological Diversity. It was one of the most important conferences with a strong impact on the future. "[I]t did a great deal towards raising public awareness of the need to take action" (Palmer 1998, p. 75).

Agenda 21 (United Nations 1992a) is the centrepiece of the Rio agreements. It is an action programme for nations to achieve sustainable development. Almost all parts of the Agenda highlight the importance of environmental education. Of particular importance is chapter 36. It "defines the term Education for Sustainable Development with four mandates: to improve access to basic education, to reorient education toward sustainability themes, to improve public awareness, and to engage in training" (Monroe and Krasny 2013, p. 17; cf. Palmer 1998; Stoltenberg and Burandt 2014). This leads to a paradigm shift from environmental education to education for sustainable development (ESD) in the following years. While EE tends to pick out environmental problems as central theme, ESD focuses on the demands of society and the participation of as many people as possible. The intention is to enable people of all ages to take an active part in social change processes with a view to the future and to help shape them. Since the ratification of Agenda 21, an immense number of local, regional, national and international initiatives, activities and programmes have been launched to anchor ESD in national education systems (Bormann 2013). To be part of the education movement each programme had to respect three areas of sustainability: (1) environment, (2) social life, and (3) economy. That is because "[e]ducation for sustainable development is based on ideals and principles that underlie sustainability, such as intergenerational equity, gender equity, social tolerance, poverty alleviation, environmental preservation and restoration, natural resource conservation, and just and peaceable societies" (UNESCO 2005, p. 28). The combination of ecological, economic and social aspects on the other hand, enabled educators to pronounce different aspects of the three, four (including cultural aspects) or five (including health) pillars that are meanwhile being discussed. As a consequence Ott and Döring (2008) pronounced the meaning of strong sustainability (starke Nachhaltigkeit) with a stronger focus on ecological targets.

Another Rio agreement in the context of EE is the Convention on Biological Diversity (CBD). Article 13, on *Public Education and Awareness*, highlights the importance of knowledge about conservation of biological diversity (United Nations 1992b). "[T]he CBD acknowledges the importance of public education and awareness as a crucial tool" (Navarro-Perez and Tidball 2012, p. 16).

The Thessaloniki Declaration adapts ESD for the twenty-first century (Knapp 2000). It states that, despite the still valid recommendations and action plans of past conferences, insufficient progress has been made. Therefore, the declaration reaffirms that education should be reoriented towards education for sustainability (UNESCO 1997).

The Johannesburg Summit in 2002 proposed a world Decade of Education for Sustainable Development (DESD) for a period of the years 2005 to 2014. "The overall goal of the DESD is to integrate the principles, values, and practices of sustainable development into all aspects of education and learning. This educational effort will encourage changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations" (UNESCO 2005, p. 6). ESD is seen as a key instrument for all forms and stages of education (Cutting and Summers 2016). "The DESD ties the ongoing interest in education to the current overarching theme of sustainable development. It is a powerful concept that could ignite the interests of people around the world to use education as a tool to shape a more sustainable future" (UNESCO 2005, p. 26).

In this context, several declarations were adopted. The Ahmedabad Declaration records the importance of education as well as environmental education for a good human lifestyle and a sustainable future for humankind. "Environmental Education processes support and champion Education for Sustainable Development" (UNESCO and UNEP 2007, p. 1). The Bonn Declaration highlights the importance of ESD for the future and a better life, by addressing topics like water, loss of biodiversity, food, health, and environmental protection. "ESD provides the skills to find solutions and draws on practices and knowledge embedded in local cultures as well as in new ideas and technologies" (UNESCO and Federal Ministry of Education and Research of Germany 2009, p. 2). Rio+20 declares a right to education. This right is independent of age, gender and state of development of the nation. Education is seen as an important tool to improve, inter alia, the protection of the environment, poverty eradication, health protection and the sustainable development of nations (United Nations 2012). The Tbilisi Communiqué recognizes the efforts of the past for "framing education around environmental protection and sustainable development, thus providing the fundamental principles for ESD" (UNESCO and UNEP 2012, p. 1). ESD is seen as "an integral element of the post-2015 education" (UNESCO and UNEP 2012, p. 6).

Today different concepts are realized along the ideas of EE and ESD. These concepts are integrated into school curricula as well as in the process of life-long learning. Many stakeholders such as environmental agencies, environmental protection centres, botanical gardens, zoos, and museums, provide access to environmental information.

In 1992, education about biodiversity emerged in the context of the Earth Summit in Rio de Janeiro. It was one of the most important conferences with a significant impact to the communication about the future of ecosystems and biodiversity. As a result of the Summit, the five Rio Agreements were adopted, among them were the Convention on Biological Diversity (CBD) (United Nations 1992b) and Agenda

21 (United Nations 1992a). The CBD proposed biodiversity education directly. The CBD entered into force on December 29th in 1993. 168 countries signed the CBD on the spot (Secretariat of the Convention on Biological Diversity n.d.-a). At the end of 2018, 196 states have ratified the convention (Secretariat of the Convention on Biological Diversity n.d.-b).

Since the beginning of the twentieth century people's awareness of global environmental problems due to the development in technology and science has grown, and consequentially the need for its protection (Disinger and Monroe 1994; Li and Zbicinski 2014). Growing environmental awareness, protest movements, the emergence of environmental movements and publications like "Silent Spring" (Carson 1962) and "The Limits to Growth" (Meadows and Donella 1972) forced politics to act. In 1969, William Stapp proposed one of the first definitions of environmental education (EE). "Environmental education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (Stapp 1969, p. 31). Starting point for the subsequent progression in developing EE further and in enhancing it to ESD were the Stockholm Conference on Environment in 1972 (United Nations 1972) and the Tbilisi Principles on Environmental Education in 1977 (UNEP and UNESCO 1978). Other milestones were the Brundtland Report (WCED 1987), Agenda 21 (United Nations 1992a), the World Decade of ESD (UNESCO 2005) and the Agenda for Sustainable Development (United Nations 2015). EE "is a multidisciplinary form of education that focuses on nature, environment and society as interdependent and inseparable entities" (Dreyfus et al. 1999, pp. 156–157). Thus, the origin of biodiversity conservation education can be found in EE.

The CBD is an attempt to reconcile ecological, economic and social aspects, perspectives and demands. Biodiversity is seen as an all-encompassing link that enables bridging and understanding between different disciplines (Jessel 2012). Three main aspects are included: (1) the conservation of biodiversity, (2) the sustainable use of biodiversity and (3) a fair sharing of the access to and the benefits achieved with biodiversity. Article 13 highlights the importance of education about biodiversity. "The Contracting Parties shall: (a) Promote and encourage understanding of the importance of, and the measures required for, the conservation of biological diversity, as well as its propagation through media, and the inclusion of these topics in educational programmes; and (b) Cooperate, as appropriate, with other States and international organizations in developing educational and public awareness programmes, with respect to conservation and sustainable use of biological diversity" (United Nations 1992b, pp. 8–9). This way the CBD acknowledges the great importance of education, training and awareness for the implementation of its goals (Ham and Kelsey 1998; Navarro-Perez and Tidball 2012). In order to contribute to the worldwide conservation of biodiversity, Article 6 of the CBD obligate party members to adopt the CBD and to convert it into National Strategies (United Nations 1992b). That way, biodiversity education (Art. 13) should be implemented into the National Strategies of each party member. In doing so, states needed to include awareness raising on biodiversity into every educational system.

Through the attempts of the governments to integrate the goals of the CBD into National Strategies and to translate them into national actions environmental educators became aware of education about biodiversity (Dreyfus et al. 1999). Two examples of National Strategies with concrete implementations of Article 13 will be presented shortly.

In 2007, the National Strategy on Biological Diversity of Germany was published. Action field C 14 implements Article 13 of the CBD. The focus of this action field is education and greater awareness. Actions like development and distribution of teaching material in order to improve the consideration of the topics of biological diversity and sustainability in classrooms and in adult education are to be implemented (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 2007).

According to the Secretariat of the Convention on Biological Diversity (2019), the National Strategy on Biological Diversity of Cuba has been in action since 1997. Its mission is sustainable development. One of its six guiding principles is 'Environmental education, training and communication at all levels' ("Educación, capacitación y comunicación ambiental a todos los niveles", Ministerio de Ciencia, Tecnología y Medio Ambiente n.d., p. 6, translated by C.B.). 'Objetivo A' deals with 'Addressing the underlying causes of biodiversity loss' ("Abordar las causas subyacentes de la pérdida de la diversidad biológica", Ministerio de Ciencia, Tecnología y Medio Ambiente n.d., p. 7, translated by C.B.). The first goal explicitly mentions environmental education for sustainable development, awareness raising and citizen participation to increase social awareness of the value of biodiversity and the ecosystem services it provides. To achieve this, topics with aspects of biodiversity should be included in the National Education System plans and programmes. In addition, educational materials should be developed (Ministerio de Ciencia, Tecnología y Medio Ambiente n.d.).

Since signing the Convention on Biological Diversity, the aim of official policy has been to raise public awareness of the need to protect biodiversity (Secretariat of the Convention on Biological Diversity 2006; United Nations 1992b; World Resources Institute et al. 1992). In order to be able to protect biodiversity, education is seen as important measure. Since biodiversity conservation education is a requirement, the state of knowledge of different target groups including the public, teachers, student teachers and students as well as their source of knowledge about biodiversity is of general interest. As there are not enough analyses about the state of knowledge about biodiversity and biodiversity conservation, the following part attempts to provide an overview focusing on the knowledge of the term biodiversity itself and the main associations of study participants when hearing the term biodiversity. Table 2 shows, there are hardly any studies about the knowledge of non-Europeans about biodiversity conservation. Existing studies suggest insufficient knowledge about the term biodiversity per se and misconceptions about its content. Associations focus strongly towards species diversity (A), followed by ecosystem diversity (B). Few people associate the genetic component (C) of biodiversity. This one-sidedness can be found throughout the world and across all target groups. The most knowledgeable population group seem to be teachers and prospective teachers.

Table 2 Knowledge in biodiversity conservation with respect to target groups (country codes according to two-digit international country code, level of knowledge according to results of analysis, A = species diversity, B = habitat/ecosystem diversity, C = genetic diversity)

Target group	Country code	Level of knowledge	Relation	References
National surveys	EU	Limited	–	European Commission (2015)
	DE	Limited	–	BMU and BfN (2018)
	US	Low level	–	The Biodiversity Project (1998)
Public	GB, NL, DE	Limited	A >> B > C	Buijs et al. (2008)
	CH	Low level	A >> B > C	Lindemann-Matthies and Bose (2008)
	GB	Low level	A > B > C	Christie et al. (2006), Spash and Hanley (1995), Department for Environment, Food, and Rural Affairs (2011)
	US	Low level	–	Hunter and Brehm (2003)
Teachers	GB	Knowledgeable	A, B, C	Gayford (2000)
	GR	Knowledgeable	–	Halkos et al. (2018)
	ID	Limited	A >> B > C	Nuraeni et al. (2017)
Prospective teachers	MY	Limited	A > B >> C	Jiwa and Esa (2015)
	TR	Knowledgeable	A, B, C	Cardak and Dikmenli (2017), Dikmenli (2010)
	RW	Knowledgeable	A, B, C	Nsengimana et al. (2017)
	CY, GB, CH, DE	Limited	–	Lindemann-Matthies et al. (2011)
	DE, CR	Limited	A > B > C	Fiebelkorn and Menzel (2013)
Students	CA	Limited	A > B > C	Arbuthnott and Devoe (2014)
	CY	Limited	–	Nisiforou and Charalambides (2012)
	GB	Low level	A > B > C	Spash and Hanley (1995)
High school students	CH	Low level	A >> B > C	Lindemann-Matthies and Bose (2008)
	DE	Low level	A > B >> C	Menzel and Bögeholz (2006, 2009)
	ES	Limited	A	Salinas Hernández (2002)
	CL	Knowledgeable	A > B >> C	Menzel and Bögeholz (2009)
	TR	Limited	A, C >> B	Kilinc et al. (2013)

The probability that the term biodiversity is known is highest with middle-aged Europeans between 40 and 54 years (Department for Environment, Food and Rural Affairs 2007; European Commission 2007, 2010, 2013, 2015) and increases with educational and social status (Department for Environment, Food and Rural Affairs 2007, 2011; European Commission 2007, 2010, 2013, 2015; Lindemann-Matthies and Bose 2008).

The main sources referring on knowledge about biodiversity conservation are, above all, school education and the media (Ballouard et al. 2011; Cross 1998; Eagles and Demare 1999; European Commission 2007, 2010; Gayford 2000; Lindemann-Matthies and Bose 2008; Lindemann-Matthies et al. 2011; Michail et al. 2007; Novacek 2008; Sustainable Development Education Panel 2000). Palmberg et al. (2015) report that for Nordic-Baltic students' school is one of the most important sources of information about biodiversity related issues. Other important sources are, inter alia, botanical gardens, zoos, natural centers and museums (Novacek 2008; The Biodiversity Project 1998).

2.9 Biodiversity Conservation Education (BCE) in Relation to Environmental Education (EE) and Education for Sustainable Development (ESD)

Education with a strong focus on biodiversity conservation can be seen as part of environmental education (EE). Environmental education on the other hand was the starting point for the development of education for sustainable development (ESD) which has a wider and more holistic horizon. However, it is also possible not to follow this sequence as a logical upward movement since widening often implies loss of contouring.

The United Nations set 17 *Sustainable Development Goals* in 2015 as blueprint to achieve a better and more sustainable future for all people (Agenda 2030). These 17 goals including 169 targets mirror the composition of working groups of the United Nations, and the recent interests of member states. The goals are characterized *as universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere* (https://www.un.org/sustainabledevelopment; accessed 3/2020). Indeed, these targets are comprising, and presumably many people can find the target which is linked to their own situation, problems and wishes. However, the ambitious goals have been criticized for their inconsistency and big anything whatever. Furthermore, they are difficult to quantify, implement and monitor (Swain 2017; Spaiser et al. 2017). One of the strongest concerns, however, is the tiny contribution of the goal to protect the biodiversity, and to focus on real sustainability of ecosystems and the environment. The targets on the other hand, indicate the powerful influence of current economic interests. Thus, the wide spectrum of partly competing targets considers biodiversity conservation and health of ecosystems in comparison with targets of further economic growth only marginally and with a strong focus on use and benefits. Unfortunately, the so-called *Sustainable Development Goals* (SDGs) are often adopted as is one by one and implemented into concepts of *Education for Sustainable Development* (ESD) without further consideration. Such procedures can widen and weaken the spectrum of pedagogic/didactic programmes and measures with the effect that the importance of environmental targets and environmental education are diminished and perished by targets of the global economy and business education. Thus, also members working on SDGs and ESD might contribute to the growth of dystopia in the world of young people.

We found the term *biodiversity conservation education* (BCE) at different webpages, for example of the Virginia Polytechnic Institute and State University, USA, and of the Biodiversity Conservation Trust, Australia. However, the aspiration of what is meant, has already been described in the Convention on Biological Diversity (CBD).

The central target of BCE is the analysis and intermediation of the relationship between nature and culture, evolution and extinction, species and ecosystem, natural constraints and human possibilities. In general the term *biodiversity* is more related to natural sciences while *conservation* is part of the ethical discourse. Thus, the input of different natural and social sciences is required. Unfortunately, curricula of schools are often related to disciplines such as biology or philosophy, with the effect that education on biodiversity conservation is falling through the net.

Biodiversity conservation as term is often associated with backward orientation and restrictions. We here try to promote another accentuation, and associate the theoretical framework and political, economic and social aspects aiming at not to surrender any single species with highly complex analyses, deliberate investments and cultural creativity. The focus is much stronger than the goal of ESD which indeed is following a bundle of different and partially competing targets. However, the scientific accomplishment of BCE in many instances is complex, and only a multidisciplinary approach might be able to enhance integrative concepts.

The following hypothetical BCE programme for secondary schools and universities may illustrate the meaning of a concrete project.

2.10 Artificial Nature Conservation and Creative Landscape Design

For the first impression, *artificial nature conservation* may look like an oxymoron (such as e.g. *civil war* or *old news*). Nature conservation in most cases tries to protect species and habitats where they naturally occur. Artificial constructions comprise human buildings, works of art and technology which are opposite to nature. However, in many landscapes and urban regions of the civilized world nature is pauperized by human influence and damage.

In regions where diverse habitats and landscape elements disappeared, where rivers were canalized, where most of the surface is used, where ecosystems and food webs are fragmented, and only small populations of the natural species pool outlast, artificial constructions in new habitat islands may help species to survive.

Many constructions such as birdhouses, insect hotels, green walls and roofs, pollarded trees, toad fences, bridges for deer crossing, or wintering grounds for bats are already established to support wild life. However, these are often established because of aesthetic reasons, to enjoy the nature, to use nature, and to prevent dead animals and avoid car accidents.

Would it be possible to stronger focus on species conservation? What information do we need to support or re-introduce rare or endangered species e.g. in intensively used industrial, urban or agricultural landscapes? How could we effectively invest money with the goal to increase the diversity and mass of native insects or to complete the food web at special sites?

Would the artificial establishment of a vertical wall of loam in a river valley support insects or kingfishers which need such walls as habitat, even if most natural undercut banks are already replaced by dams or other hydraulic structures?

Concrete questions of such BCE project might be the following.

1. Which species, habitats or species assemblages are regionally threatened? Answers and solutions may be discussed with relevant authorities and NGOs on the basis of Red Lists.
2. How can we help these species with additional constructions in a pauperized landscape, to reduce pressure on critical segments of their life cycle? Clearly, it is necessary to know much about the ecology of the target species or target habitat.
3. Which private or public site can be used for such a project? An adequate site should be searched together with regional authorities.
4. How much money is needed to initiate such a project and to be successful also in the long run? This question depends on the primary goal. Should the site support natural succession and wilderness, or should a habitat be established which regularly needs tending strategies? Should the process and success professionally be monitored afterwards?
5. How useful is it to respect and include the benevolence of the public, landscape aesthetics and citizen science?

Such a project shows that BCE can be creative, proactive and must not always follow the idea of restrictions and historical conditions as template of optimality.

3 Conclusion

Even if there was no explicit environmental education in the times prior to the twentieth century, communication, education and learning from the nature was all the time important for survival, avoidance of pain and wellbeing. It can be assumed that the amount of knowledge about the environment dramatically increased caused by the use of books and digital media whereas local knowledge disappeared throughout the history.

During the last two centuries, people became progressively aware of self-made environmental problems. The first environmental movements emerged and concepts of EE and ESD were developed during the second half of the twentieth century. These concepts came together with an institutionalisation of how and what to teach in the formal and non-formal education sectors.

Parallel to the actual development of EE and ESD, communication tools were explored and refined. At the beginning of the twentieth century, sources of information about the environment and nature were parents and family, school and university, newspapers and books. With the development of novel communication tools such as radio, television, computer and internet, information about the environment increased dramatically. Today, nature documentaries are part of the everyday television programme, and the internet overflows with information. Self-education became a possibility for everyone at every place and at any time.

The concept of ESD links two contrasting points, a better understanding of man and nature and a fairer coexistence between North and South. It adopted many objectives and principles of EE and extended these (e.g. United Nations 2005; UNESCO and Federal Ministry of Education and Research of Germany 2009). Both concepts, EE as well as ESD, aim at enabling people to participating responsibly and creatively in shaping the present and future. The self-conception of these strategies is to change environmental behaviour respecting ecology, economy and social life. Today these principles and characteristics of ESD are, due to their nature, integrated into many parts of human life, in school and out of school. It is seen as basis for an advanced and holistic (environmental) education for sustainable development.

Despite having the concepts of EE and ESD, humanity is still far away from solving today's environmental and social problems. On the one hand, human activities are the cause of these problems. On the other hand, education of practical consequences has the goal to indicate and discuss possibilities to overcome these problems.

EE and ESD are education programmes with the aim of creating the best solutions under the ethical principle of sustainable development. However, even the term *sustainable development* is part of the discussion since short-term and long-term processes, conservation and unalterability on the one hand and creation of new technologies on the other hand are discussed as being in harmony with the concept.

Modern concepts such as EE, ESD, and BCE have to respect, disentangle and analyse extremely complex relationships including gaps of knowledge. EE and ESD promote multiple and sometimes competing targets. Furthermore, due to the holistic approach the targets of ESD are partially ambiguous, while BCE is related to smaller and relatively clear targets.

Broad and holistic approaches in general can be used and misused. Today, almost every economic process and product can be labelled under the umbrella-term *sustainability*. Unintended side effects and oxymorons like *sustainable economic* *growth* can emerge because indicator systems on sustainability are often complex and inconclusive (Lyytimäki et al. 2013).

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Part II
Recent Environmental Conditions, Change and Challenges

Which processes are inevitable and which are optional?

Could it be possible to reduce the species decline in the face of a further growing human population and intensification of the global resource consumption?

How important are environmental regulations which are already there, and do we need new regulations for the survival of the global biodiversity?

How important is the knowledge of ecological, economic and sociocultural patterns and processes for the survival of the species on Earth?

In this section we discuss recent challenges with a focus on interdisciplinary analyses. Thus, the contribution of ecological facts, ethical frameworks and socio-economic processes are brought together and assessed.

Resources for Humans, Plants and Animals: Who Is the Ruler of the Driver? And: Can Resource Use Explain Everything?

Carsten Hobohm and Sula E. Vanderplank

Abstract Resources represent capability, and enable processes such as growth, reproduction, social and cultural life. All processes of life are controlled by resources. Resources are stored in living and dead biomass and in the abiotic environment. Every ecosystem is characterized by input, internal storage, internal cycling, and output of resources.

Resources are used by the species of the ecosystem, including migrating species, humans, and invasive species as they arrive. Humans influence ecosystem functions in various ways, with differential effects on biomass, productivity and species diversity. In most cases this has consequences for species diversity, which is often decreasing, but—depending on the spatial scale—sometimes also increasing.

We ask the question "is it possible to estimate the effects of human exploitation of ecosystems?" Under changing conditions the ecosystem is adapting the resource use permanently by adjusting the combination of its features. Productivity is the driver of recent conditions and biomass is storage; the existence of each is a precondition for the other. Species diversity can increase by immigration and evolution and decrease by emigration and extinction.

Humans as ecosystem engineers are key species with respect to the quantity of resources used and rebound effects on food webs, species diversity and cultural attitudes.

We delineate and discuss the meaning of the *Theory on Assembly Optimization* (TAO), which we provide here. The sequence: *resource existence*, *resource availability, resource use* and *optimization of the resource use,* represents increasing complexity with a simultaneous decrease in our quantity of empirical evidence and understanding.

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We assume that there is a general trend in the resource use by life on earth, which trends toward an optimal or most parsimonious pattern. In accordance with this concept, evolutionary, ecological and sociocultural processes influence the resource use and composition of the communities. Individuals, populations, assemblies and ecosystem properties are always composed and rearranged along changing conditions to an optimal use of resources.

Optimization of the resource use is an important principle controlling ecosystem functions—the ruler. *Diversity, productivity* and *biomass* are important drivers of the ecosystem. Changes in these properties reflect changes in the compartmentalisation and resource use of the ecosystem.

Keywords Theory on assembly optimization (TAO) · Species diversity · Biomass · Productivity · Human influence · Exploitation · Resource availability

1 Introduction

Ecosystems are most commonly composed of rock, stony or sandy ground, soil or a stage of soil development, dead organic matter, water, air, and diverse groups of living species. Thermal vents, pelagic oceans and other specialized ecosystems offer slight variations on this theme.

All plants, animals and humans need resources such as space (physical space in which to live), energy (e.g., solar energy, warmth), and nutrients or food for life at all times.

Most species also require oxygen, although many can use other gases such as carbon dioxide, on which, for example, all plants are dependent. Knowledge of the uptake, cycling and loss of resources in the ecosystem is important to estimate the effects of human influences on ecosystems, and to understanding the provisions of ecosystem services for human health and well-being (e.g., Schulze and Mooney 1993).

We here offer novel considerations as contributions to the discussion on how the species composition of an ecosystem will react under the pressure of human resource use. Furthermore, we promote the hypothesis that humans are hardly able to reduce the overall exploitation of resources effectively even when local or regional reductions or use abstinence are in place. Wherever laws, traditions or other agreements limit the resource use, e.g., to control fisheries, the limits seem to be preconditions for further or broader optimization of the resource use at global scales (International Resource Panel 2017).

Is there a general driver of the composition of species in an ecosystem? What are the most important features of the ecosystem? Is it primary productivity and/or resource use of all biota, species diversity, dominance, reproduction, longevity, or all of these independently?

Growth and death, survival, reproduction, dispersal, speciation and extinction indeed belong to the most widespread evolutionary principles of life. All biota have genetic material. The life of all individuals, populations, species, ecosystems and biomes is restricted between the limits and possibilities of their evolutionary history (genetic constraints from inside) and their environment (ecological constraints from outside). Therefore, the fate of genetic material that does not replicate or fit into the environment is extinction (Meszena et al. 2001).

How can we disentangle the interrelation of biomass, productivity and species diversity under natural conditions, and how they might change under persisting exploitation activities by a growing population of humans?

We can borrow theory from the study of economics when looking at optimization of complex systems. Furthermore, several aspects of optimization in technology and economy have been considered with respect to man, domestic animals, and cultivated plants, and can be readily discussed in an ecological context (Dixit 1990; Trepl 2005).

2 Theoretical Background

Liebig's law of the minimum is a principle discovered by Sprengel (1828). Justus von Liebig simply popularized this principle afterwards. The finding states that growth of cultivated plants is limited by the kind of resource which is only insufficiently available in relation to the need.

Extreme values are often more relevant than averages, not only in agriculture or ecology. A popular phrase tells us that a chain is only as strong as the weakest link. In ecology, extreme values often have a stronger influence on the effect than values between the extremes. Mean values are usually rather irrelevant in ecology. The so-called *Extreme Value Theory* is a combination of different theories focusing on statistics, economy, ecology, hydrology, meteorology, and others, and different authors are identified as originators. In its shortest form it says that extreme values are of higher relevance than mean values (de Haan and Ferreira 2006; Katz et al. 2005).

Why is it in this context interesting to focus not only on minima or mean values but also on maxima such as world records of ecosystem properties (Table 1)? World records are normally not far away from optimality or maximality. And optimization is often a long process of adjustment, adaptation or investment with the goal of ultimate perfection. The distinction between values of higher and values of lower ecological relevance is important in the theoretical context of resource use and resource use optimization.

There is a long discussion in biology, philosophy and social sciences about strong and moderate positions of *adaptionism, anti-adaptionism, neutralism, contingency* and *pluralism*. How important are processes of adaptation in human communities and nature? And how important are neutral, contingent and random effects (e.g., Wilkins and Godfrey-Smith 2009; Orzack and Sober 2001; Eshel and Feldman 2001; Amundson 1994; Gould and Lewontin 1979)?

Table 1 World records of biomass, productivity and vascular plant diversity (for references see text)

Property	Value	Habitat type, region	Climate
Biomass	1819 tC ha^{-1} (above-ground biomass) 2844 tC ha^{-1} (total biomass)	*Eucalyptus regnans* forest, SE Australia	Warm temperate
Productivity	8.93–9.93 kg m^{-2} year^{-1} (dry matter)	Swamps dominated by C_4 grass *Echinochloa polystachya*, Amazon	Wet tropical
Species diversity of vascular plants	89 species/1 m^2	Mountain grassland, Argentina	Temperate
	98 species/10 m^2	Semi-dry basiphilous grassland, Romania	Temperate
	233 species/100 m^2	Lowland forest, Costa Rica	Wet tropical

Both packages of theories, i.e. *Extreme Value Theories* and theories on *Adaptionism* and *Anti-Adaptionism* represent general considerations of different disciplines. They form a general frame of the theory outlined here. The following theories are more concrete and are normally discussed within natural sciences.

In ecology and biogeography there is a critical discussion about the feedbacks between environmental, ecological and evolutionary processes (*Adaptive Dynamics Theory*, Maynard Smith 1978; Wilson and Agnew 1992; Nowak and Sigmund 2004; Tilman 2004). The meaning of optimization in biological systems is increasingly recognized since modern evolutionary theory is introduced (Ferriere and Legendre 2013; van der Ploeg et al. 1999; Parker and Maynard Smith 1990; Reiss 1987; Gould and Lewontin 1979; Walters and Hilborn 1978; Maynard Smith 1978; Cody and Diamond 1975; MacArthur and Wilson 1967; Darwin 1839, 1859).

The *Resource-Ratio Theory*, going back to MacArthur (1972) and Tilman (1980, 1982, 1985), focuses on growth rates and population dynamics of competing species which use the same resources and environment. Most of the related experiments were conducted in aquatic ecosystems or aquariums (Miller et al. 2005). Tilman (2004) later on discussed niche tradeoffs with respect to resource competition, species invasion and stochasticity.

However, we want to focus on biomass/structure, productivity and species diversity as important properties of ecosystems, and assume that processes and conditions of the relationship between resource availability, population growth and competition alone cannot adequately explain the assembly because mutualism and facilitation are also so important and competition seems to be overinterpretated (Stachowicz 2001; Tilman 2004). Figure 1 shows the position of the context in a theoretical framework.

Research about important processes within ecosystems like primary productivity, community assembly rules and filter models (Fig. 2), and the influence of the environment and species pool on the local species diversity, has stimulated discussion and promoted our understanding during recent years (e.g., Feßel et al. 2016;

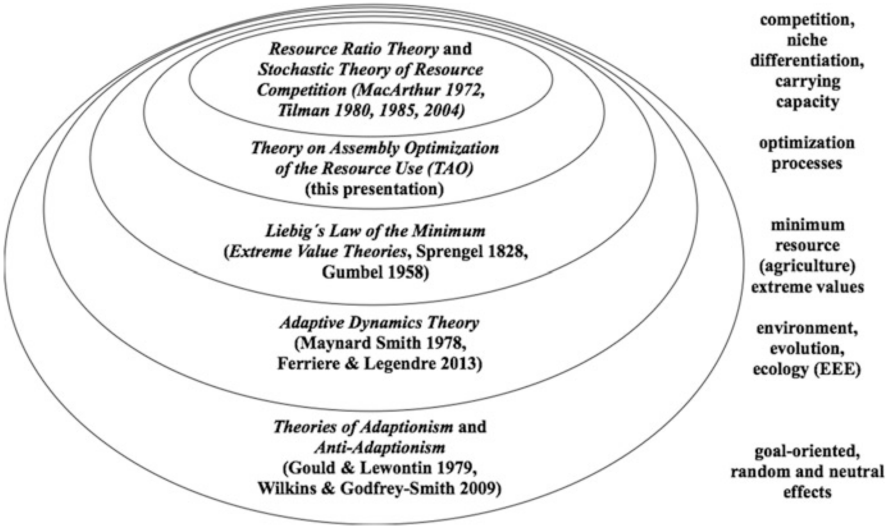


Fig. 1 Complexity and hierarchy of selected theories. The figure shows the position of the Theory on Assembly Optimization in ecosystems which we discuss here in the framework of other smaller and wider theories

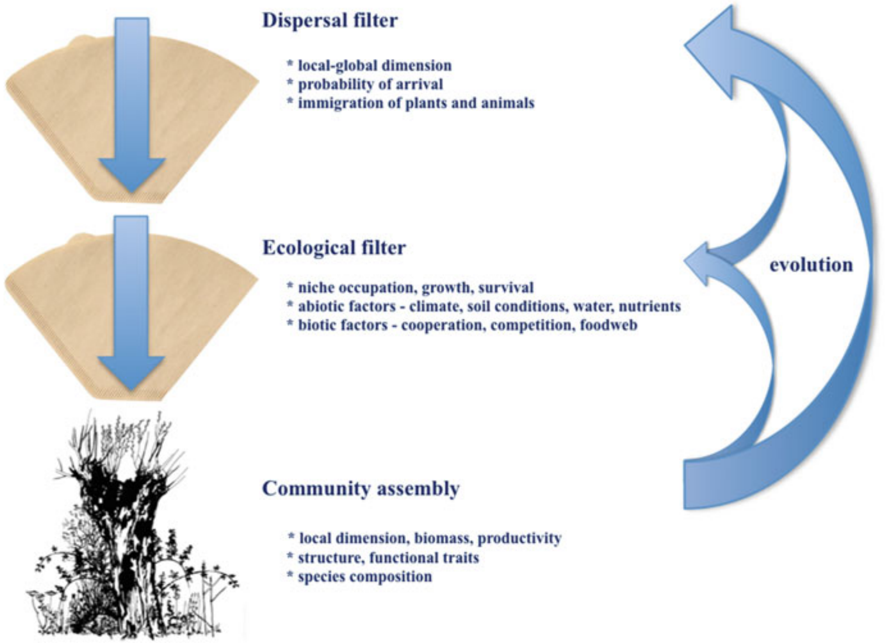


Fig. 2 Filter model combining evolutionary and ecological influences on the assembly of the community (see text for refs.)

Negoita et al. 2016; Zobel 2016; Wittig and Niekisch 2014; Hulvey and Aigner 2014; Keppel et al. 2010; Fukami 2010; Wilson 2011; Myers and Harms 2009, 2011; Svenning et al. 2009; Davis et al. 2005; Wiens and Donoghue 2004; Pärtel 2002; Hubbell 2001; Diaz et al. 1998; Eriksson 1993; Case 1983; Elton 1958).

Below, terms such as *biomass* (amount of living material per unit area), *structure* (vertical and horizontal pattern of biomass), *net primary productivity* (rate of carbon fixation in plants per unit area and time interval), *species diversity* (number of species per unit area) and *ecosystem* are used according to ecological and biogeographical standards (Forman and Godron 1986; Lerch 1991; Odum and Barrett 2005; Chiarucci 2007; Stohlgren 2007; Ellenberg and Leuschner 2010; Hobohm 2016).

Plant resources, resources for animals and human resources are often defined in a different meaning or with another pronounciation. Clearly, space, energy, water, and nutrients or food are resources of all living organisms including humans.

Distribution patterns of *money* across the globe are often called *human resources*. Are these resources different from the term *resources* used in the ecological science? Even if the transfer of money via digital media today is almost insubstantial the relevant equivalents of money are mostly natural resources, products, accomplishment and power.

Thus, in this respect the potential of money for humans is not much different from the physical potential of a lion to feed on a killed antelope. We do not see the necessity to exclude the term *money* from the term *resources* in general. Money clearly is one of the most powerful drivers of processes initiated by humans.

Are toxic components resources? Resources and toxic components are normally part of different discussions. Resources are seen in the framework of growth and survival often with a positive connotation, toxicity means illness, cancer and death and is often used with negative connotation. However, there is no principle difference between both. The effect on life depends on concentrations. The concentration holds the answer if a chemical component has a positive, neutral or negative effect. Furthermore, chemical components with different effects are often part of the same metabolism.

Thus, we here use the term resource in a very broad sense.

Many aspects of the overall context are accessible to empirical studies and statistics. However, the central discussion revolves around the logic that a stronger reason would result in a stronger effect and that optimization in average leads to higher success (yield). Due to a plethora of processes involved, because of overlaps and interactions, because of many processes that are unexplored, yet, e.g., in the context of microbiomes (cf. Zachow et al. 2016; Bragina et al. 2015; Saleem 2015), and because of the time interval between cause and effect it is impossible to prove this statement as a comprising principle at the moment. Therefore, the relationship has to be enunciated as a theory.

3 Optimization Principles

Optimization is an umbrella term comprising all processes, alterations in technology or methods that make things better—more functional, more effective, more streamlined, more efficient, and so on. It includes anthropocentric values such as beauty and pleasure, as well as more objective values such as speed or longevity. The term is used in different sciences, e.g., in economics, politics, technology, computer science, mathematics and ecology (Goh and Tan 2009; Battiti et al. 2008; Meszena et al. 2001; Dixit 1990). The meaning, relationships and differences between the terms *adaptation, trait, learning* and *optimization* are reviewed in Sayed (2014) and Baluska et al. (2018). Optimization in many instances is defined broadly and comprises processes such as adaptation and habituation (Gagliano et al. 2014).

In nature we can find optimization as a trend of many processes working at different levels of organization, during ecological and evolutionary timescales. The goal of optimization is optimality, i.e. reaching a minimum, maximum, or the best fit or functionality (e.g., the top of a bell-curve). Optimality would mean that all parts in a system are as perfect as they can be, which would imply no necessity for change. Whenever we observe change, this fact alone indicates that not everything was perfect. Optimality is a relative term. If something is optimal it is only optimal in relation to certain conditions. If the conditions change the processes have to be adjusted to reach optimality again. Thus, optimality normally is a rather ephemeral event of any given system that is subject to change (cf. Richardson 1994; Cody 1974).

Optimization of processes implies motivation (caused by convictions or emotions, e.g., avoidance of thirst or pain), competition (e.g. plants and animals—for resources including space) or cooperation (e.g. within human or vertebrate work groups and plant communities as well; e.g. Wheeler et al. 2015, Heard and Remer 2008, Trepl 2005, Thienemann 1939, 1956).

For example, at the heart of consumer theory is the assumption that consumers are individuals that try to enhance their utility, freedom, fun or whatever they pursue. In a model with several goods in which a consumer has a budget of a certain amount, it is assumed that he will choose the combination of goods with the highest effect in relation to his own goals. However, optimizing several subsystems independently will not in general lead to optimality of the whole system (Dixit 1990).

Optimization theory in evolutionary ecology dates back to Darwin's idea of favourable conditions of life, ecological variability, natural selection and survival of the fittest which he expressed in his report and subsequent biogeographical analyses from the voyage of the Beagle (Darwin 1839). Since then different optimization theories in biology and macroecology have emerged. *Natural selection, survival of the fittest, genetic variability, optimal foraging, canopy photosynthesis*, *energy efficiency* and *maximum entropy production* are keywords that exemplify optimization in its ecological context (Dewar 2010; Braakhekke and Hooftman 1999; Richardson 1994; Reiss 1987; Darwin 1859).

Optimization processes and effects are found in all biological systems; however, it is hard to prove that the adaptations of individuals, species and/or communities reflect a trend toward optimality in complex systems. Even if every subsystem was trending toward optimization of each process, the result would not be optimality, as many of the processes are contradictory. E.g. optimizing the quality of food for an animal means migration in most cases. Optimizing energy use would favor the opposite—a reduction in movement. Thus, optimality in terms of foraging and reducing the loss of energy can only be a compromise (Kratochwil and Krausch 2016; Reluga and Shaw 2015).

Survival of the fittest often predicts that fitness can be a determining factor in competition, however, in 'teams' or interactions, this may not be the case. E.g., if a strong and a weak person work together in a team the group can become more productive over time through communication (education) and/or division of labour. However, if there is no shared motivation, competition or cooperation there will also be no reason for improvement (Grant et al. 2014; Inouye 2001; Heylighen 1992a, b; Palmer and White 1994).

Mutualisms are often described as plus-plus-relationship. Other relationships, where one gains and one loses (plus-minus-relationship), are known as dualisms. The overall profit for the system should be higher in plus-plus than plus-minus relationships. Thus, the question arises why dualism has not been outcompeted during evolutionary times (cf. Clutton-Brock 2002; Hubbell 2001; Keddy 2001; Bronstein 1994)?

Plus-plus and plus-minus are describing the interspecific relationships incompletely (Bronstein 1994). Peaceful cooperation and martial competition seem to be contradictory. If cooperation would only be positive for both partners the principle should be exceedingly successful. Insect pollination for example is characterized as classical plus-plus relationship. The insect earns food, the plant profits from pollination. What could be negative for the insect and the plant at the same time? There is an expense for both parties. The plant is investing in high energy material such as nectar, the animal is spending energy by moving around. However, the overall effect may be positive for both of them.

Could it be similar with competition and other plus-minus or minus-minus relationships? We hypothesize that most if not all positive effects are combined with expenditure (energy), and the survival/reproduction itself shows that the effect is positive as long as the individual, species or ecosystem is alive and reproducing or supporting the reproduction of the descendents (cf. Holmes and Schmitz 2010; McMurtry 1991; Went 1973).

However, it is important to note how little we know about all the food webs and ecological processes such as cooperation or facilitation in our landscapes. When we look at an ecosystem we often cannot see the interdependence of the species in front of us, nor can we easily evaluate mutualisms, and often even competition is masked due to the timescales that are readily visible to us.

4 World Records of Biomass, Productivity and Species Diversity

It can be assumed that the highest values of biomass, productivity and diversity reflect responses of long lasting processes, during evolutionary times, to environmental conditions and pressures close to optimality.

The *Eucalyptus regnans* forest with a midstory of *Acacia* and an understory of tree ferns in temperate SE Australia has been identified as the highest density of living material in the ecosystems of the world (Pan et al. 2013; Keith et al. 2009). Field measurements and calculations revealed a maximum carbon density of 1819 tC ha^{-1} in living above-ground biomass and 2844 tC ha^{-1} in total biomass (Keith et al. 2009). This world record of biomass is neither combined with highest species richness nor with highest productivity. However, the relating soils were characterized as "*fertile soils with high soil water-holding capacity and nutrient availability compared with most forest soils in Australia*" (Keith et al. 2009: 11639).

The biomass and structure of an ecosystem is mainly determined by abiotic factors such as climate and soil conditions, and is assumed to be more or less independent of productivity or species composition (Neuenkamp et al. 2016; Lohbeck et al. 2015; Guo 2007).

In many cases increasing resource use by vascular plants increases the net primary productivity. However, this is not always the case (Isbell et al. 2013; Farrior et al. 2013; James et al. 2005). In general, an increasing uptake of nutrients accompanies an increase in respiration rate, luxury consumption, decreasing stability, attack of parasites, consumption by herbivores, and competition, for example. As a result, the net productivity can also decrease. On the other hand, an increase in species diversity can increase ecosystem productivity, irrespective of nutrient or water availability (Craven et al. 2016). The magnitude of the net primary productivity mirrors environmental properties such as solar energy, soil fertility, water supply, and internal cycling of the system. Many ecosystems are characterized by positive rates of productivity during the growing season and negative rates during the dormant or drought period, when respiration exceeds the productivity of living material (cf. Lebrija-Trejos et al. 2010; de Haan and Ferreira 2006; Katz et al. 2005; Golley 1994; Lindemann 1942).

Net primary productivity is extremely high if not highest in tropical floodplain swamps of the Amazon with C_4 grasses such as *Echinochloa polystachya* (up to 9.93 kg m^{-2} $year^{-1}$ in Morison et al. 2000, or 8.93 kg m^{-2} $year^{-1}$ in Piedade et al. 1994) and comparable with the productivity of fertilized maize fields in warm regions (Singh and Yadava 2014; Esser et al. 2000; Ricklefs and Miller 2000). These communities are relatively species-poor and have low biomass compared e.g. to other scrub or forest ecosystems. The relationship between high productivity and low soil fertility of tropical forest has been described as *paradoxical*. High productivity rates based on a very efficient recycling of dead matter by fungi, bacteria and small invertebrates, and nutrient cycling within the biosphere have been examined in tropical rainforests even on old, eroded and nutrient-poor soils

(Fujii 2014; Terborgh 1992). Thus, a high rate of primary productivity can be explained by both the external supply of resources and the internal cycling of resources. However, highest rates seem to be related to herbaceous vegetation of tropical swamps with C_4 grasses. Neither woody nor annual vegetation types have been shown to have such high productivity values.

The conclusions about the relationship between species diversity and productivity drawn from time series observations in natural communities, from plantations, species additions or reductions are numerous and inconsistent. Functions have been described as linear, non-linear (e.g. hump-backed), positive, negative, or independent. However, an increasing number of plant individuals and plant species generally lead to a more efficient use of the resources and to an increase of the productivity. This is particularly the case if other influences were excluded (cf. e.g. Morin et al. 2014, Cardinale et al. 2013, Simová et al. 2013, Keeling and Phillips 2007, Grace et al. 2007, van Ruijven and Berendse 2005, Braakhekke and Hooftman 1999).

Another effect seems to be contradictory, fertilization (e.g., in grassland or forest communities) often leads to a strong decrease in species numbers: Rosenzweig's *paradox of enrichment* (cf. Rosenzweig 1971). However, in the first example the (high) species diversity is the cause and the productivity is the effect, in the second example the addition of nutrients is the cause and the (decreasing) species diversity is the effect (Hobohm 2016). Still we see that the relationship is not linear, and increase in productivity can be obtained with a decrease in species diversity, yet it could be argued that the addition of nutrients creates a temporal inbalance in the system.

World records of the diversity of vascular plant species have been described from forest (100 m^2 or larger) and grassland communities (plots <100 m^2). For example, mountain grassland in Argentina and semi-dry basiphilous grassland in Romania can harbour up to 89 or 98 vascular plant species in a plot of a single square meter or ten square meters, respectively; and 233 species were counted in 100 m^2 of a tropical lowland forest in Costa Rica (Wilson et al. 2012). The forests are old growth in the wet tropics which are relatively unaffected by humans, whereas most of the rich grasslands in the temperate zone are regularly mowed (Chytrý et al. 2015; Wilson et al. 2012). This example shows that humance influence doesn't always cause a decline in species diversity. On the contrary, human influence via transportation can result in worldwide increases in species diversity. The patterns of extreme species diversity in both ecosystems are not yet well understood. However, a few basic points can be determined:

Both maxima represent late succession stages, thus, a long time of development. Both have relatively stable turnover and structure. Both are part of rich species pools indicating speciation of taxa in the same or in neighbouring regions.

Eutrophic conditions seem to exclude the development of communities with high species richness. This is probably related to the evolution of most vascular plant species under oligotrophic or mesotrophic conditions, resulting in a very different resource use optimization. Waters or soils with high nutrient levels were formerly restricted to local situations such as estuaries, colonies of breeding birds or special localities in pastures that are richly manured by herds of grazers.

The succession from white to gray dune communities in Europe is normally related to a decreasing sedimentation rate, productivity and biomass, in combination with an increase in species diversity (Petersen et al. 2014; Pott 1996). How could this type of succession be interpreted along with optimization of the resource use? A relatively high sedimentation rate of sand in the white dune is the reason for the relatively high nutrient supply, productivity and biomass of the dominant species, often the grass *Ammophila arenaria*. If the sedimentation rate is decreasing also the input of nutrients, productivity and biomass is decreasing. In this case, only a higher number of species with a more closed layer of roots under the soil surface can minimize the loss of nutrients by leaching. However, a succession with declining biomass is a special case.

The succession from pioneer vegetation to forest is often characterized by increasing productivity and biomass caused by the required space of growing shrubs and trees at least during the first succession stages. In this case, the reduced space and light at the ground results in a declining number of vascular plant species at local scales. The resulting number of species presumably reflects the evolution of vascular plants at larger scales, the wide range of species with a higher demand on light, and the lower number of shade-tolerant species (Silva Pedro et al. 2017; Ellenberg and Leuschner 2010).

The different relationships and feedbacks obviously do not allow maximization of the biomass, productivity and diversity within the same assembly.

High biomass is usually found in forest ecosystems with timber production.

High productivity is usually related to perennial non-woody vegetation units.

High diversity reflects evolutionary and ecological continuity in regions with relatively low or intermediate amount of biomass and productivity.

5 Natural Catastrophes, Invasive Species, Human Influences

Whatever the influences are, there are no such things as untouched natural ecosystems which are in an ecological equilibrium, and artificial or heavily impacted ecosystems which are not in an ecological equilibrium. The ecological equilibrium (balance of nature) was an idea during the second half of the last century to explain species compositions and ecosystem functioning (cf. DeAngelis and Waterhouse 1987; Zimmermann 2007; Kricher 2009). However, we do not see any empirical evidence to promote this hypothesis.

Sometimes vegetation structures collapse even if there is no apparent reason for this. According to Müller-Dombois et al. (1983) some *forest diebacks* are cohort senescence phenomenons due to a combination of aging and increasing environmental stress caused by depletion of certain soil nutrients.

Invasive species may represent ecosystem engineers (goats, for example) or members of a new guild (rats, for example) and cause the extinction of native and endemic species, for example on islands or habitat islands in continental regions (Fukami et al. 2006; Whittaker and Fernández-Palacios 2007; Harris 2009; Hilton and Cuthbert 2010; Jones 2010). The increase of a population of an invasive species is only possible if relating resources are available.

Humans are able to behave like natural disasters and ecosystem engineers as well. However, at local or regional scales they have already shown that they are also able to behave in a more or less sustainable manner.

Humans use landscapes and ecosystems to get space, natural products, and recreation. In the first case (space) natural ecosystems are destroyed or heavily impacted to establish settlements, infrastructure, arable land, forestry or mining.

For earning energy, water and food, ecosystems are established as, or altered to, semi-natural ecosystems. In many cases, the quality (organic farming), productivity (quantity per time) and/or biomass in total (quantity) are the targets of the use. The consumption of energy, water, food and other products under different scenarios are expected to increase furthermore within the next years or decades (cf. Hussien et al. 2017; International Resource Panel 2017; Kurian 2017; Newth et al. 2017).

Humans change structures and reduce the biomass by harvesting organic or inorganic material from the ground (including water) or biosphere. Additionally, they increase the net productivity by supplying of material such as fertilizers, water or lime. Humans alter landscapes and landscape structures, and reduce the species diversity via ecosystem engineering, i.e. by directly eliminating trees, shrubs or weeds, by hunting or using pesticides, and they can increase the local or regional species diversity by changing ecological conditions, e.g., by moderate mowing of semi-dry grassland, by planting or introducing neobiota. However, depending on the intensity, many processes can have positive and negative effects on the species richness (Pyšek et al. 2017; van Kleunen et al. 2015).

The swim bladder of a fish species called Totoaba (*Totoaba macdonaldi*), living in the Gulf of California, Mexico, is an extremely expansive commodity for the preparation of a culturally significant soup in China. However, nobody is interested in the extinction of the worlds smallest marine mammal—a toothed whale called the Vaquita (*Phocoena sinus*), which means little cow in English, and is endemic to the Gulf of California; this animal is definitely at the brink of extinction. In which way are Totoaba and Vaquita connected? The killing of the Vaquita is not intentional. The population of this species strongly declined during recent decades simply because of unmoderated and illegal resource use technologies (gillnets) for catching Totoaba, eventually accompanied with pesticide exposure and/or inbreeding depression (IUCN Redlist; see iucnredlist.org on the internet). These practice have depleted the Vaquita as bycatch and simultaneously depleted their food sources. The ecosystem functions of the Gulf of California will likely not change much when the last Vaquita individuals have gone. This could be true for many predators on top of the food web also in other ecosystems.

Landscapes that are used for recreation are often characterized by openness (1), diversity of structures and/or species (2), and water bodies (3). Large herbivors, birds or other vertebrates may even higher the beauty (4). The attractiveness of landscapes with these attributes is indicated with examples like gardening across the world, by touristic places like coastal regions, lake shores, or high mountain areas with colourful meadows and small lakes or streamlets. Openness and structural diversity can be combined to half-open landscapes with high attractiveness (Bourassa 1988; Christ et al. 2003), which are relevant for the biodiversity as well. Clearly, many if not most ecosystems of dense forest or ocean do not represent these properties. Thus, beautiful landscapes may support biodiversity and species conservation in some but not all cases. However, we want to pronounce that also the beauty of the landscape belongs to human resources. Furthermore, the heterogeneity in space and the character of a landscape including artificial light and noise is also relevant for the orientation of birds and mammals, for example. Thus, also other species may be attracted by the beauty of landscapes.

6 Carbon Cycle as an Example for Limits and Challenges of Anthropogenic Influences

The carbon cycle, which is seriously impacted by humans, may surve as an example for the limits and challenges of resource use optimization, of the relationship between culture and nature, and between human decisions and effects on the environment.

Carbon is the most important chemical element of living organisms, the carbon cycle describes the fluxes between and within the reservoirs of the atmosphere, biosphere, pedosphere, lithosphere and hydrosphere. Active pools are open reservoirs with an input and output of carbon.

The numbers in Table 1 show that the amount of carbon in the atmosphere is relatively small compared to the carbon storage in the ocean or soils, for example. The amount in living organisms is a little bit smaller than the amount in the atmosphere, the storage in terrestrial soils may be two or even three times larger.

The annual net uptake in terrestrial soils sums up to c. 2.6–3 Pg C/year and, thus, seems to be slightly larger than the net ocean uptake of c. 1.9–3 Pg C/year. Both processes already lower the increase of the amount of carbon in the atmosphere. Therefore, not only is CO_2 increasing in the atmosphere, but also the carbon storage in the ocean and in terrestrial soils. The still dramatic increase of carbon in the atmosphere results mainly from use of fossil fuels, cement production and land use change.

As a result of an increasing carbon pool in the atmosphere (2–4.4 PgC/year) the temperatures and sea level are rising in average. However, there are great regional differences in both, changing sea level and warming (World Meteorological Organization 2018).

If humans want to reduce the carbon content in the atmosphere or they want to reduce the increasing rate of carbon in the atmosphere they in general have to change the flows (fluxes). Reducing the energy production from fossil fuels is one possibility, increasing the uptake of the biosphere, soils or marine waters would be another one. Increasing the uptake of carbon in the biosphere would simply mean to increase the global photosynthesis rate. However, more photosynthesis normally means more respiration as well with the effect that this contribution of eliminating carbon from the atmosphere is limited.

The numbers in Table 2 (cf. Bar-On et al. 2018) indicate that the biomass of humans and livestock meanwhile is c. 15–20 times larger than the biomass of all wild mammals and birds together. According to data from the FAO (2018) the global aquaculture finfish production increased from c. ten million tonnes in 1990 to c. 50 million tonnes in 2015 (c. 56 in 2018; note that published numbers often refer to fishery products, not only to capture and production of finfish, and include the production of algae, mussels, and crustaceans, for example). Aquaculture is still one of the fast growing sectors of the trade of natural products and will continue to increase. It can be expected that fish produced by farming will equal the capture of wild fish within the next years or decades as the amount of wild fish harvest has been stagnant for the last 15–20 years. However, at the moment the capture of wild fish still exceeds the production of fish from aquaculture. We estimate that the amount of wild fish currently is at least five times larger than the mass of fish living in aquaculture (Table 2).

However, the numbers also show that most reservoirs and fluxes are not influencable by humans (or only little influenced). Exceptions are quantities in burning fossil fuels, cement production, land use change, agriculture, aquaculture and forestry. It is a prominent idea to eliminate carbon from the atmosphere via planting of trees. The numbers related to carbon of reservoirs in plants and fluxes, however, show that this effect under more or less realistic conditions could only be rather small (cf. Popkin 2019). This has to do with the fact that almost all of photosynthesis is compensated by respiration. E.g., a further elimination of 200 PgC via tree plantations would require the range of an additional continent and a time of at least 100–200 years. And this small effect could only be reached if we start the whole plantation right now.

The preferential area for more realistic carbon sequestration might be agricultural land, because of several reasons. First, according to numbers in CIA (2019; own calculation based on country-related numbers) agricultural fields already cover a third of the terrestrial ground. Arable land and permanent crops together cover 11%. Second, in many regions the biodiversity, water quality and productivity would profit from a higher amount of dead organic matter in the soil (Rice 2002). Third, storage of carbon in the soil would not require long distances of transportation. According to calculations in Zomer et al. (2017) the sequestration potential of just cropland soils amounts to 0.9 (medium sequestration scenario) to 1.85 Pg C/year (high sequestration scenario). These numbers are related to cropland that already exists.

Table 2 Active reservoirs and flows of carbon in the atmosphere, biosphere, pedosphere, lithosphere and marine environment (numbers are combined according to Rice 2002, Gruber and Sarmiento 2002, Lal 2008, Gruber et al. 2009, Archer 2010, Bond-Lamberty and Thomson 2010, Hughlett 2016, Bar-On et al. 2018, Earth Observatory 2019)

Reservoirs/Pools	(in 10^15 gC=PgC)
Atmosphere	600–850
Soils (pedosphere)	1500–2300
Fossil fuels (lithosphere)	3480-10,000
Ocean dissolved inorganic carbon (DIC)	37,000–38,100
Ocean dissolved organic carbon (DOC)	685
Ocean particulate organic carbon (POC: Plankton, bacteria etc. and detritus)	13
Seafloor sediments (lithosphere/pedosphere)	1000–6000
Biosphere (marine biota 3)	550–610
Plants	450–470
Bacteria (deep subsurface, excl. soil)	70
Fungi	12
Archaea (deep subsurface, excl. soil)	7
Protists	4
Animals	2–3
Arthropods	1.2
Fish (0.6 wild, 0.1 aquaculture?)	0.7
Molluscs	0.2
Annelids	0.1
Cnidarians	0.1
Livestock	0.1
Humans	0.06
Nematodes	0.02
Wild mammals	0.007
Wild birds	0.002
Viruses	0.2
Fluxes (in 10^15 g C/yr=Pg C/yr)	
Terrestrial photosynthesis (from atmosphere to biosphere)	121–123
Terrestrial plant respiration (from biosphere to atmosphere)	60
Litterfall (transfer from biosphere to pedosphere)	63
Microbial respiration and decomposition (from biosphere to atmosphere)	60
Net terrestrial uptake	2.6–3
Volcanos (release into atmosphere)	0.1
Burning fossil fuels (5.4), cement production, land use change (release into atmosphere)	6.7–9.7
Ocean uptake from the atmosphere	91.9–92
Atmosphere uptake from the ocean	90
Marine photosynthesis (salt water to biosphere)	103
Marine decomposition (biosphere to salt water)	103
Input from rivers into the ocean (including sediments, $CaCO_3$)	0.8
Sedimentation in marine sediments	0.2
Net ocean uptake (from atmosphere and rivers to ocean)	1.9–3.0
Net annual increase of atmospheric carbon	2–4.4

7 Evidence of the Theory on Assembly Optimization (TAO)

Optimization processes within ecosystems include adaptation to the environment, e.g., individual adjustment of the nutrient uptake (habituation), growth, accumulation, intraspecific and interspecific relationships, and the success of immigration and integration of new species. The more individuals, the more species, the higher the environmental specificity promoting ecological and evolutionary adaptation through speciation, the better the use and yield of resources by the assembly of the ecosystem. We hypothesize that optimization of the resource use by the biota is the moving power of change in every ecosystem as a response to changing conditions in the environment or to human's influences.

The ecosystem is an open system in which the resource use can be optimized in different ways. Every successful dispersal event and new member of the community is accompanied by a certain likelihood to enhance the resource use of the whole system (cf. Negoita et al. 2016; Mitsch 2012; Jones et al. 1994; Meeker and Merkel 1984). Together with other objections against the Monoclimax Theory (cf. Clements 1936, Whittaker 1953, Hobohm 2016) this concept might be a further argument.

Both the assembly representing active life and the availability of the resources representing potential life are both cause and effect at the same time, interrelated by an uncountable number of processes that can be optimized. Evidence for this theory can be found in recent publications such as Ferriere and Legendre (2013), Ritterskamp et al. (2016), Zobel (2016), Morin et al. (2014), Cardinale et al. (2013), Grime and Pierce (2012), Fukami 2010, Verhoef and Morin (2010), Allesina and Pascual (2008), Keeling and Phillips (2007), Pärtel (2002), Fridley (2001), as well as in many fundamental and classical publications related to evolution, ecology, phytosociology and biogeography (cf. e.g. Townsend et al. 2003, Odum 1977, 1998, Hartmann 1933, Braun-Blanquet 1928, Möbius 1877, Darwin 1859, Humboldt 1806).

8 Discussion

Is this theory simply part of the belief in a functional world that everything must be adjusted, adapted and optimized, and if not will be eliminated? Independent of the different positions and far from advancing a strong adaptionistic opinion here, the optimization/adaptation approach seems to be an important principle.

Not all processes affecting biomass, productivity, or diversity can be interpreted as logical consequence of resource use optimization processes.

There are at least a couple of antinomies, discrepancies, contradictions or dichotomies which indicate that all the processes working in the direction of optimization of the resource use can only result in compromises.

Is there any dependency or hierarchy among different optimization processes? The relationship between biomass/structure, productivity and plant species diversity

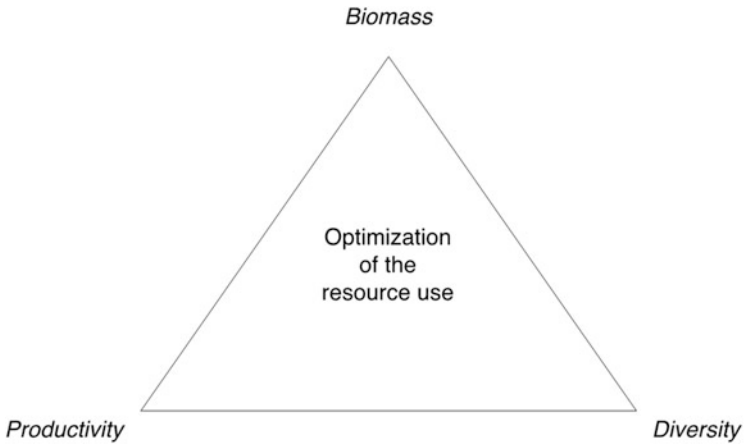


Fig. 3 Properties of the ecosystem as function of optimization processes

has been attributed to the influence of disturbance, abiotic conditions (water, energy, climate, soil), dispersal, niche specialisation, interspecific relationships, and trait variability, for example. Biomass and structure of a community depend on climate, geomorphology and soil conditions, the species diversity on structure and productivity, and the productivity on climate, soil conditions, distribution of biomass and species diversity. One general conclusion is that all these attributes are interrelated (Fig. 3; cf. Kepfer-Rojas et al. 2017, Silva Pedro et al. 2017, Shanafelt et al. 2015, Wacker et al. 2009, Fukami and Morin 2003, Huston 1994).

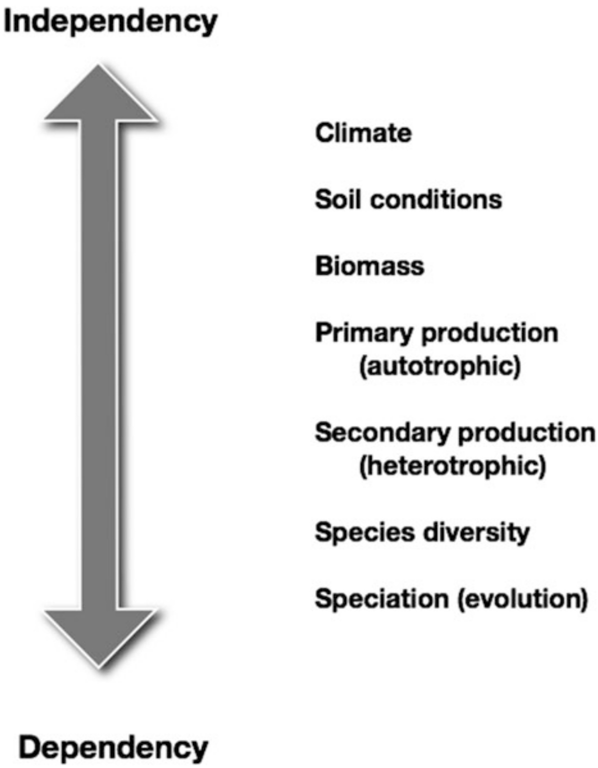
Despite a feedback of all abiotic and biotic features in the community we assume an increasing dependency of the assembly in the order *environment—ecology—evolution* which represent the three *e´s* in Ferriere and Legendre (2013). Thus, the environment has a greater influence on ecological and evolutionary processes than the other way around. The biomass, productivity and diversity of the ecosystem, for example, depend much on the local climate—e.g. temperature and precipitation—but the climate is often little affected by the vegetation at local scales (cf. e.g. Li et al. 2015, Homeier et al. 2010, Wilson and Agnew 1992). For different grassland communities Grace et al. (2007) summarized a stronger effect of the biomass production on the species richness than vice versa.

Thus, the order *climate—abiotic soil conditions—biomass/structure—primary productivity—secondary productivity—species diversity—speciation* may provide an orientation of the dependency of the ecosystem (Fig. 4) even if exceptions are numerous.

This or another order would indicate a hierarchic system and therefore a system of more or less dependent underlying optimization processes.

On the other hand, the world records of biomass, productivity and diversity represent different climates, biogeographical regions, evolutionary histories, species pools, ecosystems, and life forms. Thus, they are more or less independent.

Fig. 4 Relative meaning and dependency of ecosystem properties (for explanations and refs. see text)



Highly effective use of resources may maximize growth rate, competitive power and reproduction of individuals of the community. The disadvantage could be that maximal resource exploitation can result in emptiness, i.e. in total elimination of one or more resources. Moderate long-term use, in contrary, guarantees not to eliminate the resource and might maximize the prospects of survival for the metapopulation. The roots of the debate about this dichotomy are hundred years old, when ecologists discussed the individualistic concept with a pronounciation of competition (Gleason 1926) and the organismal concept, pronouncing the meaning of positive effects for the community, i.e. mutualism and facilitation (Clements 1916; Tansley 1920).

Optimization of the resource use means adaptation and maximization of biological processes by accumulating, recycling and investing as many resources as possible, and minimizing their loss. It is clearly not the only power forming the assembly or constituting the ecosystem since neutral effects such as genetic drift exist, and even negative effects can be observed.

The resource use by plants, animals and humans can normally be optimized under constant, regularly oscillating, and more or less *normal* environmental (dry/wet, warm/cold, day/night, etc.) conditions. However, where in the nature would it be possible to find constancy or stability? The *law of conservation of mass* is more or less true for chemical elements at global scales. It says that the mass of elements is constant. However, constancy of resources that are used in specific environments can hardly be observed at local or regional scales because habitats are open systems.

Extreme events such as volcanic eruptions, land slides, or extreme drought or cold may destroy ecosystems, alter ecosystem structures or reduce the biodiversity dramatically. In the case of extreme events which totally destroy all the biomass, productivity and diversity, the resource use will be reset in relation to the amount of resources that could be used. In many regions gradually and long-term increasing resource use by a growing number of individuals and species which enhance their teamwork over time can be interrupted by sudden harsh or catastrophic events which stop the biotic use of resources, and the adjustment of the resource use may start again with the sequence of immigration, niche occupation, growth and reproduction, cooperation, competition, succession, together with a more and more effective resource use, and in parallel—in a long-term perspective—changes of genetic material (evolution). Environmental catastrophes, but also human activities, and even other ecosystem engineers such as megaherbivores in savannas can turn former positive adaptations into uneligible adaptations.

In economy, both producers and consumers try to maximize something due to particular constraints and interests—profit or utility, for example. For understanding the whole economic system of producers and consumers it is important to find out which one of the parties is more powerful. Are the producers controlling the consumers or vice versa? Or are both parties equally controlling the counterpart? Most likely, none of the parties can act without respecting or cooperating with the other one. Furthermore, both parties agree in the protection of utilities that humans gain from natural resources which has been called *resourcism* (Uggla 2010, 84).

In the ecological community, the whole system can be divided into several parties and every ecosystem is more complicated than an economic system managed by humans. To uncover not only important processes of the ecosystem but the improvement of the processes remains difficult because also the levels of the hierarchy can alternate; where resources, producers and consumers such as therophytes, cryptophytes, hemicryptophytes, chamaephytes, phanerophytes, epiphytes, herbivors, predators, parasites, decomposers, including humans, are working together, cooperating and/or competing, where uncountable intraspecific and interspecific relationships together with random effects are relevant, where microbiota of associated microbiomes are extremely important.

Is it in this context necessary to focus on the whole ecosystem or would it be possible to explain the features of the ecosystem by looking at the ecological position of individuals only? Individuals have their own specific genetic material and environment. They are more or less independent of each other. However, also here the whole is more than the sum of its parts. Many interspecific relationships such as pollination cannot be explained as the sum of individual processes or behaviours. The ecology and evolution of a flowering plant individual that necessarily requires insect visitation for pollination cannot be explained by its own morphology or anatomy alone.

Resources, biomass, productivity and species diversity of the ecosystem are accessible to standard field and laboratory methods in ecology. The adaptation/

optimization approach of such complex systems as the resource use of an ecosystem is still not accessible.

Even if biomass, productivity and species diversity of the local assembly are connected, the world records of these properties represent different regions (continents), different evolutionary histories and species pools. This fact indicates more or less independent underlying optimization processes.

We still do not know much about the effects of changes in species composition, biomass and/or productivity on the amount of single and limiting resources and on changing compositions of resources and their feedback. Thus, the theory delineated here can only be an intermediate step of the discussion about the improvement of processes behind the assembly.

At the moment, it reflects plausibility and is a simple working model to fuel discussion.

If optimization of the resource use is a general driver of the biomass/structure, productivity and diversity in ecosystems it is possible that different aspects in human communities and history including the relationship between human population growth, culture and land use might be at least partly comparable (cf. Axinn and Yabiku 2001; Bongaarts 1996; Jolly and Torrey 1993; Boserup 1981).

Despite diverse cultural performances of abstinence the global exploitation and use of energy and material is continuously growing until today (Krausmann et al. 2009). It seems to be difficult to protect whole biomes against exploitation of resources and increasing resource use by humans if the population is still growing. If in a worst case scenario it will not be possible to limit the overall resource use what could be the solution for the ecosystems?

There are many ideas about solutions, and many positive examples are put forward. The use of ecosystems by humans does not necessarily have negative impacts on the biomass, productivity and/or species diversity, although such influences most likely will alter at least one of these properties.

Nature conservation and landscape management can protect landscapes, parts of ecosystems and species directly. An uncountable number of organic ingredients in nature such as proteins that might be used for health and food would be protected indirectly. In nature conservation areas all over the world certain activities are restricted. Thus, not only the quantity of the global resource use matters, but also the quality of the management at regional scales, e.g., the use of social and technical solutions in fisheries to reduce bycatch or to arrange spatial partitioning of the use intensity. In many cases species are threatened with extinction not because of the resource use but because of dissipation of resources (bycatch, pollution, many others, cf. IUCN Red List on the internet).

It is clearly both, expensive and uneffective to produce und use material for human's life such as plastic or medicine and to pollute other ecosystems with these substances without any idea of recycling the resources that have gone. Thus, we support the hypothesis that resources could be used more effectively and with a long-term perspective if the exploitation of ecosystems and species would be modified, channeled and reduced in a cultivated manner and with a much smaller output of waste and production of endangerment for species.

The use of resources must not be intensified but could definitely be optimized.

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A Framework for Evaluation of Normative Solutions to Environmental Problems

Karl Christoph Reinmuth

Abstract This article deals with the question of how normative solutions to environmental problems can be evaluated. Terms like 'challenges', 'problems', or 'solutions' can (normally) only be understood against a normative-evaluative background. We identify environmental problems and challenges, such as the threat to ecosystems and the loss of biodiversity, through evaluations. If we want to overcome environmental problems and challenges, we must act. In order to coordinate and guide our actions, we must commit ourselves to general norms. So, rules (laws, standards, etc.) are important means of overcoming certain environmental challenges. The use of rules can be justified by showing their quality. However, specific hurdles arise in the evaluation of (good) rules. In order to overcome some obstacles, the components of the presupposed evaluations need to be made explicit, and one needs a conceptually and substantively convincing evaluation framework. The article has two aims. The first goal is to develop a framework for the evaluation of rules or rule systems and to present the corresponding evaluation components. Furthermore, it is shown at which points normative-evaluative decisions are to be made, when argumentative reasoning is to be given, and that we have to distinguish between different types of arguments. Furthermore, I will analyse which evidence is needed in these different arguments and which obstacles one has to deal with in getting the required evidence. The second concern of the article is to illustrate how some moral criteria for the evaluation of rules can be specified and how the moral quality of environmental rule systems can be examined. For this, the theory of strong sustainability, as developed by Konrad Ott and Ralf Döring, will be used as a yardstick for the moral evaluation of a set of rules. It will also be shown how argumentatively substantiated evaluative propositions can be obtained with the help of a moral theory.

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1 Introduction: The Need for a Framework for Evaluation

If a certain sense of ‘challenge’ and ‘solution’ is presupposed, i.e. a difficult task, a problem which is to be solved, and something which *should* be done, it is not surprising that ‘challenges and solutions’ (or other terms such as ‘problems’) are normally understood against a normative-evaluative background. We identify problems by using evaluations and we use evaluations for finding good or at least better solutions. In order to evaluate in a methodically secure way, the role of normative and axiological considerations is to be made explicit. We have to understand the evaluation process for developing solutions to environmental problems.

Evaluations are made in different contexts and they accompany our actions in various forms. We judge the actions of others, objects, states and much more. We do so by taking different standpoints and applying different criteria and standards (Fournier 1995; Lumer 1990; Taylor 1961; von Wright 1963). So, we can judge the loss of biodiversity from a moral point of view, or the beauty of a forest from an aesthetic point of view. And, for example, criteria for good rules may be validity, effectiveness and harmlessness. To know whether these criteria are fulfilled, we rely on evidence-based arguments in which normative or axiological premises are also formulated. These premises are shaped on the basis of standards. Only if we make explicit the normative-evaluative questions we can (1) make clear the differences between facts and norms/values (and understand why facts are relevant for evaluations) and (2) have (hopefully and possibly) good arguments for specific normative solutions.

Philosophy can play an important role here, since making the evaluation components explicit already helps to identify and locate possible points of (dis)agreement. Furthermore, there are convincing ethical theories that can be used to specify the evaluation criteria. Evaluations are widespread in everyday life and in the sciences and they receive very high attention in social science and pedagogical disciplines (Döring and Bortz 2016; Scriven 1999; Crabbé and Leroy 2008). There are also diverse approaches to methodological questions of evaluations. In the following, the logical aspects are more likely to be in the foreground.

The article is structured as follows: After some introductory remarks on the need for a framework for the evaluation of rules and rule systems, the main components of an evaluation will be presented. If a moral theory is to be used for moral evaluation, it must be stated which evaluation criteria are to be applied. In the following, some criteria of a moral evaluation of rules are introduced. In discussing the criteria, I will briefly clarify the term ‘rule’, the components of rule formulations and the functions of rules. Depending on which moral theory is used, the criteria can be designed differently. Here, the theory of strong sustainability developed by Ott and Döring will be used for this purpose. This theory is briefly presented in the second section of the article. Some results of the evaluation of the German Fertiliser Ordinance ('Düngeverordnung') using the theory of strong sustainability will then be presented. In ecosystems, fertilization can have serious effects on the environment, for example, on biodiversity. It will be shown that tentative and rough evaluations of the currently applicable fertiliser rules are possible. However, it is also shown that further detailed work is unavoidable in order to meet the requirements for a comprehensible evaluation. In a final step, the problems and potentials of the evaluation approach pursued in this article are pointed out.

2 Rules as Tools: Changes in Norms as Solutions to Problems

If we want to solve a problem, we want to know what causes the problem and we want to know how we can change the causes or effects so that we can solve the problem. If a problem is caused by human activity or can be solved by human actions, one way to solve a problem is to change behaviour. An important solution to environmental problems lies in the change of human actions. We can change human actions by changing physical conditions, e.g. by using physical boundaries or material changes, or by changing normative conditions. Since actions are guided by rules or norms, changing rules can be an important contribution to solving environmental challenges. This is where rules come in handy. This is what rules can be used for. So, in order to solve a problem by using rules, we need evidence about the causes and evidence about the impact of rules for changing the causes. In using rules, we are restricted by different constraints—we cannot use *any* rule, but we should use good or right rules. Since rules are themselves the subject of critical appraisal (e.g. in legislative processes) a comprehensible evaluation of rules is desirable.

An important part of environmental legislation and policy-making consists in designing and setting rules in order to solve problems (Kinzig et al. 2013). For the following presentation of some ideas from a philosophical perspective and with a special interest in "the meeting point of legal, political and social philosophy" (Hart 1979, 828), the intricacies of the policy-making process will not be considered. It is taken for granted that one important part of policy-making consists in designing and setting rules in order to solve problems and it is assumed that arguments play a crucial role in policy-making. The argument-structures which will be presented are idealizations. They are meant to capture the rational-logical not the psychological side of the argumentation coin. Policy-making agents do not only have a moral duty to set morally good rules but are also often legally obliged or politically motivated to set the right or good rules. In the policy-making process we find at the different stages arguments for justificatory propositions that policy agents should design or implement certain rules. Which rules are the right, good or even best ones and should be used to solve environmental challenges? To answer these questions, we have to evaluate rules.

If one wants to justify one's actions one has to rely on the quality of the used means. If a policy-making agent should use the right or good rules, then the agent has to know what the right or good rules are. And if the agent knows what the right or good rules are and sets these rules, she can justify her use of the rules accordingly. Because we very often want a justification before acting we want to know whether the means we can use are good. So, while one can measure the success of implemented rule systems, we often want to know beforehand whether a rule system satisfies the criteria and so could be used justifiably.

Since we have to evaluate rules for policy-making we need a theory of evaluation. If rules are tools (von Hayek 2013), they will be evaluated like other tools, instruments or artefacts. So, we will use different criteria and for these criteria we will consider the possible uses of the tools. The criteria for good or right rules can vary enormously. And even if the criteria are fixed, a lot of effort is invested in the question whether they are fulfilled by the rules. If the process of evaluation is considered as a reasoning process, one can identify different criteria-related arguments. In these arguments we often rely on evidence for supporting the claim of the argument. So, because our main evaluation objects are rules, we have specific problems getting the needed evidence.

When we talk about evidence in the context of policy-making, we have to achieve a better understanding of rules and rule uses. This seems accepted by social scientists who worked on public policy and is mentioned by (Brennan and Buchanan 1985, xv): "We play socioeconomic-legal-political games that can be described empirically only by their rules. But most of us play without an understanding or appreciation of the rules, how they came into being, how they are enforced, how they can be changed, and, most important, how they can be normatively evaluated." And (Ostrom 2005, 17 f.) wrote 20 years later: "Until recently, rules have not been a central focus of most of the social sciences [. . .] there has not been much interest in examining where rules come from or how they change. [. . .] we have to dig below and learn how rules create the set being analysed." A theory of rules and rule uses is not only central, because policy-making is very often a choice of rules within rules (Brennan and Buchanan 1985; Vanberg 1994), but because for the evaluation of rules we need evidence about the functions of rules and the possible uses of rules. But because people use rules differently it is sometimes difficult to predict the possible effects of the rule uses.

3 Outline of an Evaluation Framework: Evaluation Components

A transparent evaluation should highlight the individual components as clearly as possible and formulate them well, so that the argumentative steps can be understood and assessed. To show how complex evaluation processes can be, the different evaluation components are presented (Table 1).

The terms ‘evaluandum’ or ‘evaluand’ are commonly used in the literature. Taylor introduces the term ‘evaluatum’ as the object “which is graded or ranked” (Taylor 1961, 4). The object(s) to be evaluated is/are called evaluandum or evaluanda. Frequently, items are evaluated that are selected to represent an entire item type. The evaluation statements obtained are then generalised and the selection of the representative object must meet certain requirements. The object actually selected for evaluation is called the evaluatum. Evaluandum and evaluatum can, but do not have to, coincide. In the following, the term ‘object of evaluation’ is used for both the evaluandum and the evaluatum and it is assumed that they coincide.

The various components can and should each be considered in their specific peculiarities, and evaluation research has concentrated accordingly on these various aspects and formulated corresponding recommendations that should be observed for successful evaluations (Rossi et al. 2006; House 1980). In view of the extensive considerations involved, these cannot be dealt with in detail here (see Ott/Reinmuth in this volume for the role of values in evaluations; in Reinmuth 2020 the evaluation components and the evaluation of rule systems is discussed at greater length). Rather, the focus will be on the various arguments that can be linked to evaluations.

Table 1 Evaluation components

1—Evaluator	An agent (actors and agencies, e.g. students of an event) evaluates
2—Evaluandum	An action, an object (a house, a meal), an actor (a person, a pupil, a doctor), an event (outbreak of the 2nd WK), unreal circumstances (the action of Zeus), abstract objects (rules, teaching contributions) or hybrid forms [policies (normative-axiological systems), programs (rules, agents, events)]
3—Point of view	From a moral, aesthetic, rational, legal,... point of view
4—Respect	Under axiological or normative regard/respect
5—Yardstick	According to a yardstick (...)
6—Criteria	According to certain criteria (...)
7—Standards	Using certain standards (. . .)
8—Data/Evidence	On the basis of existing data, facts, assumptions, information on (characteristics of the object of evaluation)
9—Degree of fulfilment	By checking the degree to which the criteria defined by the standards have been met
10—Evaluation judgment	And arriving at an evaluation judgment on the basis of the degree of fulfilment and the weighing of the criteria
11—Evaluation proposition	And the agent affirmatively expresses her judgement, where appropriate, in an evaluation proposition.

So only a few components of evaluations are discussed in more detail. However, it can be shown which argumentative steps are necessary, which complexities are connected with evaluations and which hurdles can occur in the identification and assessment of relevant evidence. The use of a moral theory can make clear how some components of evaluations can be completed, and that moral evaluations claiming intersubjective plausibility are quite possible.

4 Evaluative Reasoning

To capture the different components of evaluations we can consider the rational process of evaluation "as a process of reasoning" (Taylor 1961, 9). So, we are interested in the argumentative substantiation of evaluative propositions. The main argumentative steps in an evaluation are to conclude that the evaluation criteria have been fulfilled on the basis of certain data (on the properties of the objects to be evaluated) and defined standards, and to infer the (relative) quality, value, merit, worth, correctness or similar of the object to be evaluated on the basis of the fulfilment and weighing of the criteria. The standards determine when certain criteria are fulfilled. By defining standards, one operationalizes the criteria—one specifies which characteristics an object of evaluation must have in order to fulfil the criteria. Taylor calls this the "operational clarification of standards" (Taylor 1961, 9). In the context of the terminology chosen here, this is regarded as "operationalisation of the criteria". Barry (1990, 193) formulates a similar distinction: "It is of considerable importance to make a distinction between standards and criteria [. . .]. The criterion remains the same from one context to another; the comparison affects only the standard. The criterion for 'being larger than' is the same whether one is talking about dogs or horses; it is only the standard defining the minimum size which an animal has to be before it can be called 'large' which varies from one kind of animal to another." However, the operationalization of the criteria through the formulation of standards is to be understood in a broad sense that does not only include the use of quantified formulations (cf. Taylor 1961, 12).

The following argument is formulated in a standardized way: The argumentative speech acts are explicitly stated ('It holds __' indicates the act of asserting, 'Since __' indicates the act of adducing-as-reason, and 'Therefore __' indicates acts of inference). In this article I use the term 'proposition' to refer to the linguistic entities normally called 'sentences' because the latter word is reserved for a unit which is composed of an illocutionary operator and a proposition. For a presentation of the language conception used here see (Siegwart 2007).

0 It holds

This rule is a good one.

1 Since

This rule fulfils the criteria C_1, C_2, . . ., C_n.

2 Since

If a rule fulfils the criteria C_1, C_2, . . ., C_n then it is a good rule.

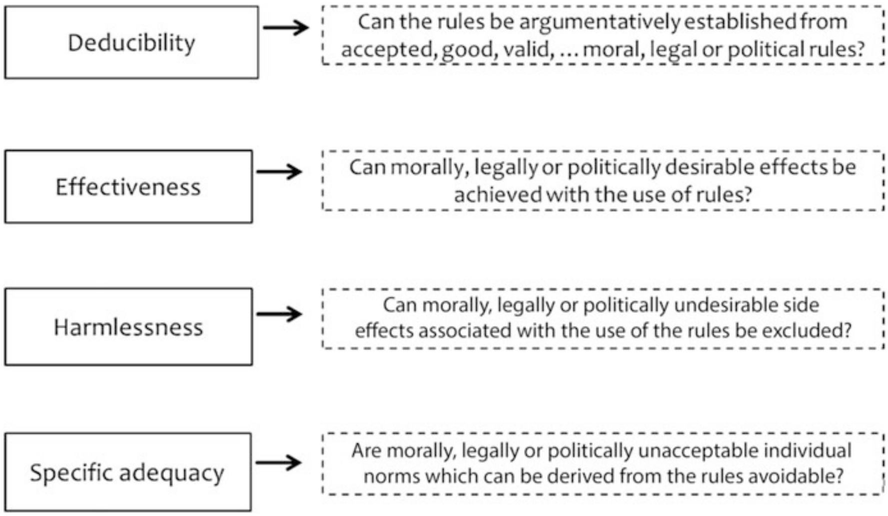

Fig. 1 Moral, legal or political criteria for the evaluation of rules

3 Therefore This rule is a good one.

Some remarks about the standardized argument should be added: The thesis that a certain rule is a good one opens the argument as a claim in *line 0* and finishes the reasoning as a conclusion in line 3. In *line 1* a proposition about the fulfilment of some criteria is adduced as a reason. The proposition is normally based on empirical observations. So, we need evidence that the criteria are (at least to a certain degree) fulfilled by the rule. And for knowing which evidence we need we should formulate our criteria in a precise way. The standards of a yardstick specify which properties an object must have in order to (not) fulfil the criteria—or to fulfil them better or worse. This is determined by the standards applied in each case. We use standards for the specification or operationalisation of the criteria. For establishing a proposition about the fulfilment of criteria we argue again. For example, we can say that if a rule has the characteristics $E_1, E_2, \ldots$, then the rule fulfils the criterion C_1. If we want to know whether the criteria are fulfilled by certain rules, we can rely on evidence-based arguments, where different arguments are related to the different criteria. In order to know what evidence is relevant and needed, we have to consider these different arguments. With this rule-centred view on the role of evidence in arguments related to policy-making we can consider some of the obstacles for getting the required evidence. The general reason in *line 2* formulates the conditions for the goodness of a rule—the weighing of the criteria can be incorporated into the formulation of the proposition. From line 1 and 2 the claimed proposition can be inferred in the *line 3*. In this case, an evaluandum was evaluated axiologically. If, for example, the correctness of an action is evaluated, one evaluates normatively. Even then, appropriate criteria of correctness must be applied.

Figure 1 shows an example for an evaluation yardstick which consists of different criteria. For the purposes of this article it does not matter if we consider the criteria to be moral, legal or political.

To justify the use of certain rules we need answers to the formulated questions. And in order to answer these questions comprehensibly, we need arguments which establish in a well-argued fashion the corresponding propositions. In these arguments we need some evidence which supports empirical claims.

In the following, the ways in which we can get answers to our criteria-related questions, the role of evidence, and some of the obstacles for getting the answers are discussed. Criteria form a main component of yardsticks and must be developed for an evaluation. For example, the use of the criteria ‘deducibility’ and ‘harmlessness’ requires normative statements from which rules can be derived, or statements about what morally questionable side effects are. The next step is to show how the criteria can be specified using a moral theory. The theory of strong sustainability developed by Konrad Ott and Ralf Döring will be used for this purpose. Rule systems are often evaluated with regard to their moral quality. Such judgements are often spontaneous, unsystematic, or made on an ad hoc basis and this can cause faults within the evaluation process. So, it seems reasonable to reflect on the evaluation practise itself and consequently to try to design or to adopt an evaluation method which results in fewer faults.

4.1 The Deducibility Criterion

The question whether or how rules or norms can be argumentatively substantiated is one of the core questions of moral and legal philosophy. One way to answer this question is to provide a validation concept and to show how rule formulations can be expressed in a form which allows analysing the argumentative substantiation of rules in a formal way. For this an intuitively plausible rule-understanding is used, which is based on the findings of Max Black, which were further developed by Geo Siegwart (Black 1962; Siegwart 2010, 2011). According to this understanding, a rule is a general, conditional action guide. Rules determine in which situations it is permitted, required or forbidden that agents of a certain kind perform certain acts. Accordingly, there are several components of rules: agents, situations, deontic modes and actions. There are several rule-concepts. The term ‘rule’ is here used with a relatively broad meaning. This broad usage of the term ‘rule’ is for example found in the work of the mentioned social scientists Buchanan and Ostrom and in the work of the legal philosopher Herbert Hart, who characterized the law as a rule system (Hart 1994).

A rule in standard form is a generally formulated if-then proposition in which the agents and the situations are mentioned in the if-clause while the deontic mode and the acts are specified in the then-clause. The rule quantifiers are due to the generality of rules. And you can find in Fig. 2 the four components in the agent, the situation and the action formula, and in the deontic phrase, respectively.

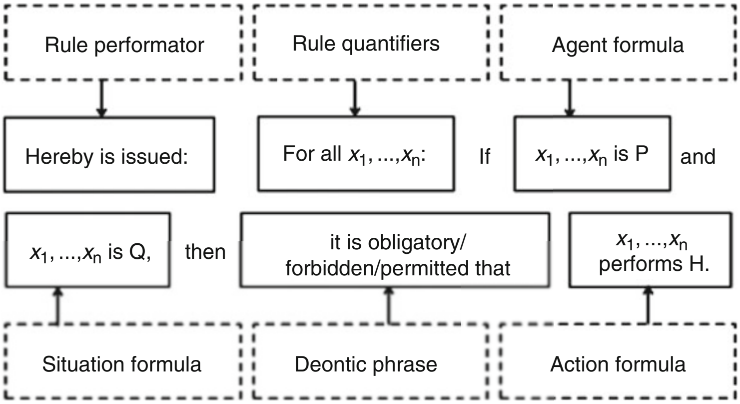

Fig. 2 Components of rule sentences in standard form (adaptation of Siegwart 2010, 43)

This standard or explicit form of rule formulations has an explicit logical-grammatical structure; the use of the rule propositions in inferences can now be assessed by logical standards. And this is crucial for our purposes. However, when using these formulations for validating rules one has to be aware of the interaction of rules and the application contexts. It is often hard to integrate all exceptions and exemptions in explicit rule formulations. As noted above, an important part of policy-making consists in designing, setting and evaluating rules in order to solve problems. Very often, policies contain rules or are part of rule systems themselves. There is a lot more to say about rules, the elements of rule systems or the intimate relation between rules and sanctions. But this first clarification is hopefully enough for the purposes of this article.

Before the deduction of rules is going to be addressed, the inference of specific norms from rules is discussed. The use of norms in arguments is necessary for the action guiding use of rules. Norms are guides for actions, so one can say that rules are general conditional norms. Beside rules there are at least two other kinds of norms: Unconditional individual norms and conditional individual norms. With those terms the application of rules can be illustrated. Suppose that Mister Hart, a chess player, wants to move one of his pawns. If we instantiate a chess rule, we get a conditional individual norm, as indicated in Fig. 3.

This example illustrates that rules have their action guiding and action evaluating force for certain situations and certain agents only through conclusions inferred from them—the application of rules is the only way to show that in a situation certain individuals' acts are prescribed, allowed or forbidden according to that rule. So, without individual norms rules could not fulfil their tasks of action guidance and action evaluation.

The inferences from rules are regulated or one can at least distinguish between correct or incorrect inferences. But not only inferences are guided by rules but also the speech acts of asserting and adducing-as-reason. As you can see, in the argument a factual reason is adduced and most likely some evidence supports it. The language

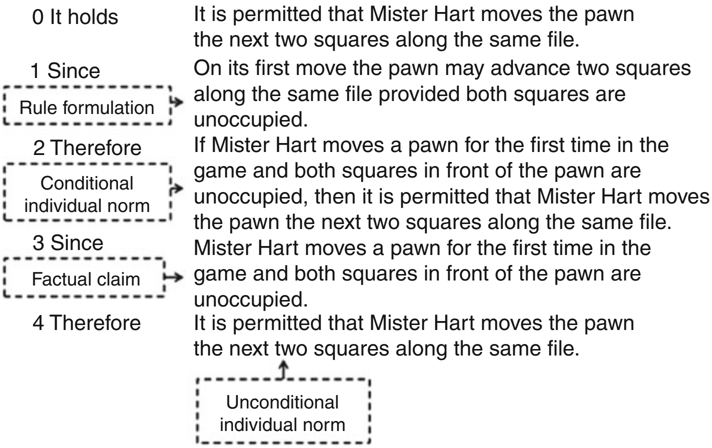

Fig. 3 Inferring an individual norm

entry rules "which take us from experiences [. . .] to such utterances" (Putnam 1981, 11) inform us about the conditions under which we are allowed to adduce an empirical reason.

As we know from the discussions about the legal concept of evidence, the evidence used in the contexts of rule application should be relevant. And because, as Hare said, "evaluative properties supervene on descriptive properties" (Hare 1984, 3), evidence is relevant because our evaluation results supervene on the empirical reasons or the evidence which supports these reasons. So, the results of the evaluations are dependent on the facts and would be different if the facts would change. Thereby we are rationally bound to accept different evaluative propositions if new facts would lead to different evaluation results. But we are certainly bound relative to our criteria: We can either accept the evaluative result or change our criteria. But if we use certain criteria, we will need certain evidence relative to these criteria. So, specific evidence is relevant relative to different evaluation standards or criteria.

But not every relevant evidence is allowed. Beside the relevance condition, the empirical reasons used in the application of rules should be true or at least well-supported. And the rules governing the admissibility of evidence are relative to normative systems. But because evaluation supervenes on evidence, different rules for evidence lead to different evaluation results. So, these rules are themselves relevant for the outcomes related to the rule system and should be evaluated too.

What applies to the deduction of individual norms does similarly apply to the deduction of rules and thus to the application of the deducibility criterion. We always need evidence for a correct rule application, but what kind of evidence is needed is relative to our used rules for evidence and the applied rules. And these considerations are slightly the same in the context of rule deduction and thus in the application of the deducibility criterion. Not only individual norms can be deduced but rules can also be deduced by adducing as reasons normative and further non-normative propositions, which express, for example, conceptual or empirical relationships. And, as in the context of rule application, there are different context-relative rules for the use of evidence. And not only the rules for evidence differ between different normative systems but also the rules for the use of the rules. Such rules guide, for example, the interplay between different rules. If reasoning from rules is accordingly rule-driven itself, these rules of reasoning are to be evaluated and one can consider to what extent context-relative practices are taken into account. So, one of the main challenges for applying the deducibility criterion is to reconstruct a (where appropriate context-dependent) system of rules of deontic reasoning (Alchourrón and Bulygin 1971).

4.2 The Criteria of Effectiveness and Harmlessness

The criteria of effectiveness and harmlessness are normally used in the policy-making context and the problems of using empirical evidence are relevant at this point, because we need some evidence about the probable consequences of the uses of the rules to apply these criteria. And normally we want to know beforehand whether the rules fulfil the criteria. Such ex ante considerations have to use assumptions, for example concerning the behaviour of actors. So, these criteria refer to the functions of rules and the possible consequences of rule uses. Rules are often characterized as means or instruments. So, they can fulfil specific functions. In general, rules can be used to evaluate and criticize actions, justify actions, coordinate actions, learn and teach actions, predict actions and facilitate decision making.

There are some obstacles for obtaining the needed evidence for knowing whether the criteria of effectiveness and harmlessness are fulfilled: First, we have to formulate the effects and specify them in such way that we have clear indicators or so-called success criteria. For the problem of an operationalisation of goals a pragmatic way is commonly used for obtaining the needed data. Furthermore, we have to consider collateral damages. It needs to be examined what unintended or undesired side effects are to be expected or can be observed and which side effects are acceptable. But even if one could achieve consent about the goals or possible indicators, there would be several ways of achieving them and the choice of the means is a much-contested field. Who shall bear the burdens? Whose acts should be forbidden or demanded—that is whose freedom of action should be constrained?

One of the bigger problems in this examination would be that one needs a great deal of information for the analysis and evaluation of a rule system. The uses of rules are guided by rules too. But there are not only different rules for using rules in different normative systems but it is not guaranteed that these rules are applied. And because, as Ostrom said, "[r]ules, the biophysical and material world, and the nature of the community all jointly affect [. . .] the likely outcomes achieved" (Ostrom 2005, 16), we need information about the style of rule uses in the community in question. Maybe that is one of the reasons why randomized controlled trials (RCTs) cannot tell you everything you need to know: "You are told: use policies that work.

And you are told: RCTs–randomized controlled trials–will show you what these are. That's not so. RCTs are great, but they do not do that for you. They cannot alone support the expectation that a policy will work for you" (Cartwright and Hardie 2012, ix).

Ex ante considerations have to use assumptions concerning the behaviour of actors. The choice of the appropriate cognitive and motivational assumptions about actors has an important effect on the evaluation of rule systems. In economics, actor models are used which ascribe to the actors certain capabilities and intentions. The economists Brennan and Buchanan, for example, argued for the use of the homo-economicus model for the comparative evaluation of rule systems. They note explicitly that this model does not describe empirical facts but is useful for theoretical and methodological reasons (Brennan and Buchanan 1985, 74).

But the homo-economicus model is confronted with a dilemma: If one chooses the model for prediction and assumes that the actors comply with the rules, then one disregards the problem that some people disobey the rules. But if one does not assume that the actors follow the rules in the first place then one has the problem of the rationality of being guided by rules and one cannot assume that the rule system can exist at all. The problem of the intentional and rational rule-following of a homo economicus was presented for example by the philosopher Edward McClennen (2004): If rules prescribe or forbid an act in a situation, then this act is supported by (the balance of) reasons or not, so there is no better option or there is a better option. If the act is supported, then the rule is irrelevant. If the act is not supported, then it would be irrational to follow the rule. So, rules are either irrelevant or it is irrational to follow them. McClennen's reaction on this dilemma is inter alia the recommendation for changing the standard model of rational rule following.

The point of the last remarks is that we need theoretical assumptions about the behaviour of actors and the different style of rule uses. But the use of an actor model should not only be supported by methodological reasons but also by evidence because "unrealistic assumptions [. . .] lead to untenable explanations of social phenomena" (Anderson 2000, 200). But theorists shouldn't use over-simplified actor models which are blind for some kind of evidence for the ex-ante evaluation of policies. Or to say it with Elinor Ostrom: "The embarrassment that we face is that policy analysis has yet to develop a coherent understanding of how our subject matter should best be expressed, how rules fit or don't fit together to shape observable behavior and outcomes" (2005, 181).

4.3 The Specific Adequacy Criterion

The legal philosopher Herbert Hart (1994) indicated repeatedly that in a normative system the rule agents "apply the rules themselves to themselves". So, rules without acceptance are either non-used (and so ineffective) or it is very expensive to ensure the required rule use. For the evaluation of rule systems we need evidence that the rules will be accepted. In the process of application there can occur unacceptable evaluations of cases. If individual norms which are used in such evaluations can be gained from the rules, this will be often discovered by the rule users. So, we need to consider the experience of the rule users which apply the rules themselves to themselves.

And because expertise-based policy-making can be in contrast to consensus-based policy-making there is a possible tension between the criteria of effectiveness and specific adequacy. So, we have to take into account the experiences of the rule users and the actual grade of acceptance.

Because we should use different criteria we should rely on different sources for evidence. Technocratic expertise shouldn't undermine democratic feedback processes and for the evaluation of policies questions of rule uses and application should not be left out. Therefore, one further evaluation criterion could be the revisability of the rule system.

5 The Moral Evaluation of a Set of Rules Using the Theory of Strong Sustainability

In this section, the theory of strong sustainability as developed by Konrad Ott and Ralf Döring will be used as a yardstick for the moral evaluation of a set of rules and it will be clarified how argumentatively substantiated evaluation statements can be obtained with the help of a moral theory. The sustainability theory in the version elaborated by Ott and Döring is a rule-centred moral theory: Ott and Döring establish the central rules of the theory of strong sustainability. The objectives of the theory are derived from the rules: The achievement of goals must correspond to the observance of the rules (Ott and Döring 2008, 177).

The theory of strong sustainability is an anthropocentric approach, since the rules are argumentatively substantiated above all by the intergenerational obligation to leave necessary conditions for a good life to future generations. Since a certain amount of natural capital is necessary for a good life and since there is uncertainty about the right amount, we should preserve rich and diverse stocks and funds of natural capital. Since, for example, we cannot foresee what significance or benefit certain animal or plant species will have for future generations, we should preserve them. The theory of strong sustainability is anthropocentric, but extremely powerful and also far-reaching in its normative demands, since all necessary conditions for a good life are to be ensured—the theory of strong sustainability regards not only the conservation, preservation, and restoration of nature. And since there is also uncertainty about the right degree for these other conditions, some efforts are needed to be able to provide the necessary conditions for a good life. The need for a certain amount of natural capital for a good life is central to the theory of strong sustainability, which, unlike weak sustainability approaches, rejects the idea that natural capital can be substituted by other types of capital (e.g. human capital) and that people can live a good life with man-made or human capital alone.

A central rule of the sustainability theory is the so-called Constant Nature Capital Rule. The rules of the sustainability theory further consist of an investment rule, which requires an investment in the improvement of scarce natural capital, and usage rules, which concern the use of natural resources. The rules must be linked to appropriate prescriptive guidelines (Ott and Döring 2008, 170). These serve as bridging principles for the further specification of the CNCR and the other sustainability rules and can thus be interpreted as application principles: "These management rules can be used, albeit not in the sense of a strict derivation, to develop further concretisations, such as quantified environmental targets. It is precisely from the fact that evaluations are necessarily incorporated into the concretisation of the sustainability principle that the demand is justified for objectives and strategies to be developed in transparent and open procedures" (SRU 2002, 67; translation by KCR).

In order to use the theory of strong sustainability to formulate the criteria for moral evaluation, not only must the rules be formulated in such a way that further rules can be inferred from them, but it must also be pointed out what are desirable consequences and undesirable effects with respect to the theory. The rules of the theory are not only a guide for action but also carry some notions about sustainability targets, i.e. the targets which can be subsumed under the conservation-target. Furthermore, the values of the theory are also relevant for the question as to what ends are morally desired or what ends are morally good. As mentioned, if one chooses such a moral system, one of the further problems is the problem of deriving subgoals or specific ends from the moral system. One needs this step, since if one wants to evaluate specific rule systems like an environmental code one can hardly use a rough criterion with a demand for conserving biodiversity. Rather the criterion needs a specification about what counts as 'conserving biodiversity' in the context of the rule system at hand. But there are many indicators or so-called success criteria and the discussion about the design and choice of adequate indicators is rather vivid. I leave the problems of operationalisation of sustainability goals aside. Along with that goes the problem of value clashing since often one has to satisfy different wishes and one has to establish a hierarchical order of values. Rules fulfil a bridging function (Baurmann et al. 2010). They provide guidance for actions that attempt to integrate diverse values and to do justice to different values (see Ott/Reinmuth in this volume for the role of values and norms in environmental evaluations). This also makes it clear that the establishment of rules is associated with compromises and trade-offs.

The evaluation of the moral quality of environmental regulations will be illustrated using an example: The German Fertiliser Ordinance ('Düngeverordnung'). The question of the section in its specific version is: How can the moral quality of the German Fertiliser Ordinance be evaluated using the strong sustainability theory?

The Fertiliser Ordinance regulates fertilisation on agricultural land in Germany. In Germany, fertilisation is regulated by a number of regulations, but the Fertiliser Ordinance is particularly important. The Ordinance regulates when, where, what and how fertilisers may be applied. Fertilisers are applied to about 50% of Germany's surface area. The requirements of the ordinance depend on the type of operation, the type of fertiliser and the characteristics of the arable land. In principle, fertilisation should be based on the nutrient requirements of the plants. Nutrient requirements are calculated on the basis of measurements and guide values. Problems related to fertilisation have often been pointed out in recent decades (BLAG 2012; Taube et al. 2013). Fertilisation is associated with a number of negative effects on the environment, some of which are considerable. It leads to soil, water and air pollution and thus to negative effects on natural resources. Each type of fertiliser is associated with certain problems: These negative effects can be avoided or reduced if fertilisation is carried out in such a way that the nutrients are supplied precisely and in line with nutrient requirements. The rules of the Fertiliser Ordinance are therefore of particular relevance for avoiding the negative effects of fertiliser operations (SRU 2015). In 2017 the Fertiliser Ordinance has been amended because the EU Commission has taken Germany to court for inadequate implementation of the Nitrates Directive and the Fertiliser Ordinance is intended to implement the Directive. In 2018, the European Court of Justice ruled that Germany had failed to fulfil its obligations under the Directive by adopting the Fertiliser Ordinance of 2006. However, on basis of the ruling of the European Court of Justice, the European Commission also saw a need to adapt the Fertiliser Regulation from 2017. Accordingly, the Fertiliser Regulation was again amended in 2020.

Now that the theory of strong sustainability and the Fertiliser Ordinance have been briefly presented, it will be illustrated how the evaluation criteria developed with the aid of sustainability theory can be used to evaluate the Fertiliser Ordinance. Since fertilisation has many and massive effects on natural resources, the Fertiliser Ordinance is a central set of rules from an environmental and agricultural point of view and the question to be addressed in the following is: How can the moral quality of the amended version of the Fertiliser Ordinance be evaluated? The criteria are treated in the same order as above.

5.1 The Deducibility Criterion

The criterion of deducibility concerns the question of whether the rules of the rule system can be argumentatively established or, in the variant related to sustainability theory, whether the rules can be argumentatively established on the basis of the statements of the theory of strong sustainability.

Specific obligations for farmers can be derived from the rules of sustainability theory by drawing on further conceptual, empirical and normative premises. These further premises supplement or expand the sustainability theory and the quality of these background statements or their fit with the sustainability theory would have to be discussed separately. For example, the theory of sustainability gives rise to a rule according to which the supply of fertilisers is necessary in order to maintain soil fertility and to produce useful plants, and from this rule one can derive the rule according to which farmers may fertilise.

However, sustainability rules can be used to establish a massive restriction on the use of phosphorus as a fertiliser. A major fertilisation problem is being discussed under the banner of ‘peak phosphorus’ (Cordell et al. 2009; Steen 1998): Since phosphorus in mineral fertilisers is obtained by mining of phosphate rock, and these phosphorus reserves are limited, not enough phosphorus will be available in the medium term without complex recycling processes. For example, it is very difficult to recover a large part of the phosphorus in waste water, and it is also difficult to recover the phosphorus lost as a result of soil washout into surface waters.

Since the economically usable phosphorus reserves are limited and there is no physically and functionally equivalent substitute for phosphorus according to current knowledge—i.e. the phosphorus deposits are not substitutable—it is necessary for farmers to use only as much phosphorus as can be recovered through measures within the framework of a closed-loop economy. The amount of phosphorus used for fertilisation would have to depend on the current potential for recycling, which is not very high. This illustrates how strong the decline in phosphorus use should be, i.e. there will be enormous losses in yield. If one compares the phosphorus rule obtained from the theory of strong sustainability with the rules of the Fertiliser Ordinance concerning the use of phosphorus in fertilisation, it can be seen that the rules of the ordinance are not compatible with the derived phosphorus rule, because the use of mineral phosphorus is not limited with regard to recoverability.

The fulfilment of the deducibility criterion for every rule of the fertiliser regulation cannot be presented in this context. However, it is clear that the criterion is only partially fulfilled by the regulations.

5.2 The Effectiveness Criterion

The criterion of effectiveness concerns the question of whether the use of the rules can achieve desirable or good effects. With regard to the theory of strong sustainability, the criterion is fulfilled if the relatively desirable effects according to the theory of strong sustainability can be achieved by using the fertilisation rules.

When plants grow, they extract nutrients from the soil. If the plants are harvested, the nutrients are also removed and in the medium term the soil would be leached out without a renewed supply of nutrients. Soil fertilization serves to maintain soil fertility, to increase and improve yields and quality, and also to reuse animal excrements and organic waste, etc. Fertilisation means that less soil has to be kept available for agriculture and sufficient food can be provided. Without the addition of fertilisers, only one third of current yields could be achieved.

There are numerous evaluations of the effects (on nutrient supply, environment, farms, etc.) of the use of fertiliser rules (see for example BLAG 2012 with further references). On the basis of the results of these evaluations, it can be established that, if the fertiliser rules are used correctly, numerous effects of these rule uses are desirable from the point of view of sustainability theory. The rules of the fertiliser ordinance thus fulfil the effectiveness criterion.

5.3 The Harmlessness Criterion

The criterion of harmlessness concerns the question of whether the use of fertiliser rules is associated with undesirable or bad side effects relative to the sustainability theory.

The rules of the amended Fertiliser Ordinance can be used in such a way that undesirable effects occur relatively to the sustainability theory. The effects vary depending on the fertiliser used. For example, the application of liquid manure on agricultural land causes ammonia emissions. These can be significantly reduced by rapid incorporation into the soil. The fertiliser rule for incorporation in the Fertiliser Ordinance of 2017 (§ 6, para. 1, sentence 1) can be used in such a way that incorporation takes place too late to prevent eutrophication and thus biodiversity loss (SRU, WBAE, WBD 2016). In the 2020 version, a reduction of the incorporation period to one hour was not made binding until February 2025, although immediate incorporation would be even better (Möckel 2020). Ammonia emissions can also lead to the release of nitrous oxide, which contributes to the destruction of the ozone layer and the anthropogenic greenhouse effect (Härtel 2002, 52).

The application of animal excreta also leads to unavoidable nitrogen losses in the form of ammonia in the atmosphere, but above all also as nitrate in groundwaters, flowing waters and surface waters, even if it is incorporated quickly. The quality of water bodies is greatly reduced by these nitrate leaching processes. The nitrogen compound nitrate is then contained in groundwater in such high quantities that the water has to be purified with cost-intensive technical solutions. But not only nitrate, but also heavy metals, pollutants and medicines reach the soil via animal fertilisers.

The chemical extraction of nitrogen is again very energy-intensive and—as has already been mentioned—phosphate is degraded and, unlike nitrogen, there is no chemical process for phosphorus extraction. In addition, the mined phosphates contain heavy metals and other pollutants.

The use of mineral fertilisers also has a negative effect on the humus content and there is a decrease in species diversity because, for example, certain plants fix nitrogen and only grow on low-nitrogen soils and mineral fertilizers do not require crop rotations. Compost and sewage sludge, which contain valuable nutrients and humus, are traditionally used in agriculture as organic fertilisers. The secondary raw materials (biogenic municipal waste) are also very inexpensive suppliers of nutrients and humus, as they are recycled waste. On the other hand, compost and in particular sewage sludge contain pollutants that are hazardous to the environment and health, such as chemicals, heavy metals and pharmaceuticals.

All in all, it can be said that the use of the fertilisation rules can lead to serious side effects (Douhaire 2020). Thus, the harmlessness criterion is not fulfilled.

5.4 The Specific Adequacy Criterion

The criterion of specific adequacy concerns the derivation of non-acceptable individual norms. This criterion could also be added to the criterion of harmlessness. Many farmers are dissatisfied with the fertiliser rules because they sometimes have massive difficulties in implementing them—e.g. when storing liquid manure. If the fertiliser ordinance leads to individual cases requiring exceptions, the rules should be changed or compensation provided.

This illustrates that even if some rules are good relative to certain specified criteria, the rules to be set cannot be evaluated relative to the sustainability theory alone. They should satisfy further moral or political principles—like accountability or principles of good governance. For a comprehensive moral appraisement of environmental rule systems, one needs various criteria of appraisal. The scope of the presented approach is limited by the choice of the four criteria. As was mentioned before, the results of an evaluation are valid only relative to the used criteria. The nearer and wider context is essential for the evaluation. In the case of the Fertiliser Ordinance, we have to presuppose the political framework and the other fertiliser rules and further laws. So, for the evaluation one has to be familiar with these facts. So, it is hard work to judge that a particular rule or rule system has a high moral quality.

5.5 To Obtain an Evaluation Judgment

How is the moral quality of the Fertiliser Ordinance to be evaluated in the light of the examination of compliance with the applied and specified criteria?

The main argumentative steps in an evaluation are to conclude the degree of fulfilment of the evaluation criteria on the basis of certain data on the properties of the evaluandum and certain standards and to infer the quality, value, or goodness of the evaluandum on the basis of the fulfilment of the criteria and the weighing of the criteria. The selection of the criteria was not justified and the weighing and interaction of the criteria were not discussed in this article. It was also not discussed whether the criteria of effectiveness and harmlessness are related to the actual use of rules or to such uses of rules that could be made by malicious or benevolent actors, respectively. Rather, the aim was to make clear that the theory of strong sustainability can be used to evaluate environmental rules and regulations and that rough evaluations of the currently applicable fertilisation rules are possible.

Even without a more detailed analysis (see for a more detailed evaluation of the Fertiliser Ordinance Reinmuth 2020), it can be stated that the Fertiliser Ordinance does not completely fulfil the criteria laid down. It was not clearly established to what extent the criterion of specific adequacy is met. Although the Fertiliser Ordinance fulfils the effectiveness criterion, the deducibility criterion is only partly fulfilled, and the harmlessness criterion is not fulfilled at all. Thus, the moral quality of the Fertiliser Ordinance is not high.

Fertiliser rules could be designed to reduce undesirable impacts and be compatible with sustainability rules. For example, fertilisation could be based more on the actual nutrient potential of the soil and not on possible yields, which would not be achieved due to prolonged rainfall, for example, and thus nutrients would not decrease. Crop rotations and nitrogen-binding plants are good alternatives. Retaining samples could also be requested so that the determination of nutrient requirements can be verified. It would also make sense to oblige biogas plants to prove who has purchased their fermentation residues – a kind of double-entry bookkeeping for nutrients.

6 Summary and Outlook: Problems and Potentials of the Evaluation Approach

In this article, components of evaluations were first emphasized. In order to illustrate the difficulties and complexities of evaluations, the argumentative evaluation components were then analysed in more detail. It has been shown that we should distinguish between different arguments in the context of rule evaluation: On the one hand, we have arguments for a rule proposition and arguments for the proposition that this rule is an effective and harmless means for some purposes. On the other hand, there are arguments for evaluative propositions which state that this rule is a right, good or even the best one and arguments for justificatory propositions that we should use (design, implement, follow...) certain rules. Finally, some of the problems and potentials of the presented evaluation approach will be addressed. As we have seen, it is quite possible to use a moral theory to design a yardstick that provides plausible evaluation criteria. However, it is sometimes not clear which further background considerations may be assumed. The example of the evaluation of the fertiliser ordinance with the aid of a sustainability theory illustrates the high cognitive effort of a systematic and transparent moral evaluation of a relatively straightforward legal rule system. Considerable efforts are involved in the evaluation of rules and regulations. In order to be able to obtain reasoned evaluation statements, the results of social, natural and legal research must be taken into account when determining the degree to which the criteria have been fulfilled. The hurdles that arise when answering the questions relating to the criteria or checking their fulfilment are enormous. If we take seriously the idea that policy-making is above all a choice of rules within rules, we have to consider also the rules which guide our evaluations, arguments and uses of evidence. When we talk about evidence in the context of policy-making we have to achieve a better understanding of rules and rule uses—for example to predict the possible side effects of certain policies. And because the use of evidence is imbedded in the use of evaluations and arguments we have to consider theories of evaluation. And we should argue about the criteria we want to use for the evaluation of policies. In a more technical vocabulary, one could say that I argued against restricted ways for thinking about the evaluation of policies, like that of a consequentialist economist who uses only the criterion of effectiveness and designs the rule user as a homo economicus. But we shouldn't exclude empirical considerations. So, we shouldn't just use the deducibility criterion for justifying the use of rules. We shouldn't be strict deontologists and disregard evidence or empirical propositions about actual rule uses in our evaluation of rules.

Because our evaluative and normative propositions supervene on evidence, it plays a significant role: different evidence binds us to accept different evaluative or normative propositions. But this role is restricted by the standards we use, so we could change our standards. Or, to put it otherwise: We (sometimes) disagree about criteria—and accordingly deem different evidence to be relevant for knowing whether we could justifiably implement the policy. And because the choice of a policy is a choice within rules we accordingly need good rules for the use of evidence in policy-making related arguments.

The application of the deducibility criterion raises questions concerning the reconstruction of moral theories and the adequate formulation of rules. Furthermore, it must be clarified how rules are applied and how they generate further rules in interaction. The insight formulated in the social sciences applies to the criteria of effectiveness and harmlessness: It is very difficult to carry out rule impact evaluations. We face problems of assessing rule compliance and enforcement. In addition to unclear cause-effect relations and the difficulty of making counterfactual considerations, the analysis of the achievement of objectives is also complicated by the overlapping of different sets of rules. For example, various factors can have an influence on the actions of farmers, like cross compliance, economic factors (demand, fertiliser price) and market incentives (subsidies—positive sanctions), measures concerning other rule systems like water protection measures or action programmes of the Nitrates Directive, preferences of farmers or negative sanctions.

These considerations illustrate how difficult it is to involve all those concerned in corresponding discourses on evaluations of normative solutions to environmental problems. However, this approach enables us to perform a comprehensible evaluation and to discuss the quality of the arguments in a precise way. Without a detailed discussion it is not clear which rules are to be changed and which alternative means could or should be used.

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Environmental Evaluation between Economics and Ethics: An Argument for Integration

Konrad Ott and Karl Christoph Reinmuth

Cecil Graham: What is a cynic?
Lord Darlington: A man who knows the price of everything, and the value of nothing.
Cecil Graham: And a sentimentalist, my dear Darlington, is a man who sees an absurd value in everything and doesn't know the market price of any single thing.

—*Oscar Wilde, Lady Windermere's Fan*

Abstract A philosophical analysis of value systems, which are used for decision-making in dealing with biodiversity and nature, can contribute to an informed choice of a value system. In particular, philosophical reflections on the role of values in argumentation, judgement and decision-making, on different types of values and their relationship to norms can provide information on which functions value systems must be able to fulfil and which criteria they should fulfil. This article discusses classificatory maps of values and patterns of reasoning. The Total Economic Value, the Ecosystem Service approach and different value systems being conceived in environmental ethics will be analysed and their strengths and weaknesses will be presented. It is argued that a comprehensive and integrated synthesis of existing approaches is possible if serious solutions to difficult philosophical problems associated with environmental evaluation are taken into account.

Keywords Values · Norms · Principles · Rules · Value systems/Schemes · Nature (value of) · Evaluation · Valuation · Total economic value · Ecosystem service approach · Environmental ethics

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1 Introduction

There is no lack of approaches to the valuation of natural and semi-natural entities in the context of environmental protection issues, especially with regard to biodiversity on the different levels of genomes, populations, species, and ecosystems. With reference to valuations, arguments are made for and against conservation, restoration, sustainable utilization, access and benefit sharing, and other ways of dealing with such entities. Different, sometimes competing value systems are used, which are based on different presuppositions, but nevertheless can overlap. In the following article, some value systems (= schematized orderings of types of values) will be subjected to a philosophical analysis, since the lack of systematic unification is a deficit, and an analysis can contribute to a well-founded choice of a value system. A systematic theoretical step towards conceptual unity and the clarification of the respective presuppositions helps constructive exchange and can open the view to more urgent political questions. This article is dedicated to a discussion of existing approaches to valuation and evaluation and identifies avenues for possible synthesis.

The basic idea can be formulated as follows: Value systems are important tools for the evaluative classification of complex issues. They are also part of a scientific ideal of operationalizing concepts and often quantify value questions. Philosophical considerations, however, have deeper questions of evaluation in mind and a desired conceptual unity must systematically combine both practical considerations and reflections on (sometimes oversimplified) presuppositions. In particular, philosophical reflections about the role of values in argumentation, judgement and decision-making, about different types of values and their relation to norms can provide information about which functions value systems must be able to fulfil and which criteria they should fulfil. This article analyses approaches to environmental evaluation and presents a discussion of their strengths and weaknesses. It argues that a comprehensive and integrated synthesis of existing approaches is within reach if solutions to difficult philosophical problems related to valuation issues are considered.

This article is structured as follows. In the first part, we discuss the axiological concept of value and highlight the role of value systems in valuations and evaluations (Sect. 2). We then analyse various value systems that have been proposed in various disciplines in the humanities and social sciences for mapping environmental values. There is the Total Economic Value (TEV) scheme, the Ecosystem Service (ESS) approach and various value systems designed in environmental ethics (Rolston 1988; Kellert 1997; Krebs 1999; Muraca 2011; Ott 2010). TEV and ESS are often seen as economic schemes, which gives them the general suspicion of "neoliberal thinking" and the repugnant commercialisation of nature on the part of some environmentalists. We will see under which conditions such accusations are justified. While the TEV is clearly economic in scope and method (Sect. 3), the case is more complex with regard to the ESS (Sect. 4). Both TEV and ESS are anthropocentric, while all value systems in environmental ethics pay attention to the demarcation problem, considering inherent moral value for natural beings (Sect.

5). The idea of a uniform ("synthesised") valuation scheme does not require a final and perfect solution to the demarcation problem, but such scheme should not be limited to anthropocentrism. In Sect. 6, we argue that the categories within TEV and ESS can and should be integrated into the essential thought patterns of environmental ethics discourse. As we shall see, valuation schemes can either obscure or reveal underlying philosophical and ethical problems. Our strategy is to use such schemes for revealing.

2 Value Systems and Evaluations

Since ancient times, philosophy has reflected on the status on categories named "values". The philosophy of values is termed "axiology" since then. Sociology, psychology, history, and economics affirm subject-based axiologies since the beginning of the twentieth century. Values are treated as social facts (Durkheim, Weber) from the perspective of observers. The many differences in between values can and should be explained by history, psychology and sociology, while philosophers quest for validity and the (ultimate) grounding of values. Differences between values can take different axiological correlations: peaceful coexistence, indifference, mutual support, respectful tolerance, contrariness, conflict, clash, contradiction. Conflicts over supreme values (nation, religion, socialism, purity of race) may lead to rebellions, civil wars, and revolutions. In Germany, values of natural monuments, unspoiled landscapes, endangered indigenous species, wilderness areas etc. have enriched the spectrum of societal values since the Romantic movement (Ott 2016a).

Nobody doubts that values of environmentalists conflict with those of a liberal consumer culture. According to our modern lifestyles, values of different spheres can be combined. Clearly, beautiful valleys, sparkling waterfalls and a sunset on the beach can be valued as being "good" for naturalists. One can, however, also value a robust car by which one can reach remote sites and can also enjoy a comfortable hotel room with ocean view at the coastline. Most of us value a high-tech camera for spots and sceneries. Economists argue that reasonable utility-functions would combine preferences to different goods and commodities as to maximize the individual good. High-end tourism often combines natural sceneries with luxury accommodation. Such high-end eco-luxury lifestyles, however, look morally repugnant, because not all people can realize them. In such cases, values come under moral attacks. Is it unjust to enjoy a holiday season in the outdoors as long as not all working class people on planet Earth can enjoy paid holidays? It seems fair to say that egalitarian social movements have specialized on grounding such attacks on "privileged" values, even environmental ones. Thus, appreciating values of natural entities does not escape moral critique against unjust privileges.

2.1 Philosophical Axiology

Most contemporary philosophers see individual humans as the grounding "locus" of values. Human agency is intrinsically value-oriented. If an agent wishes to reach a goal, she puts a value upon it. To agents, it seems impossible not to value. We will focus on self-conscious agents making value judgements on a daily base. If so, valuing is nothing special, but it belongs, as a mundane practice, to everyday life. Humans enjoy values and they dislike disvalues. Values are perceived, experienced, and expressed from the first-person perspective and such first-person-expressions are articulated within cultures via language. Therefore, any ordinary language must include phrases and attributes expressing (dis)values. Such expressions are used in value-judgements. Value-judgements can refer to commodities, artefacts, works of art, aesthetic performances, dishes, hobbies, parties and so on. Axiology becomes analysis of value-judgements and asks how cultural debates about value-judgements are to be performed and substantiated (= justified).

In Habermasian discourse ethics (Habermas 1981), the problem of how to substantiate values remained unresolved. To Habermas, emotional and expressive value-judgements refer to the validity claim of sincerity ("Aufrichtigkeit"). Some value-judgements, however, implicitly claim rightness, since supreme values as liberty, peace, health, democracy etc. are addressed. Validity claims for rightness have a different status than the articulation of preferences. While values remain within the particularities of cultures to Habermas, only general rules can be recognized within discourse as being valid. Speech about values, however critical, does not reach the mode of discourse. To Habermas, (particular) values and (universal) morals ultimately fall apart. Contrary to Habermas, we wish to bring values closer to discourse and, by doing so, shed some light onto the intermediate zones between axiology and deontology.

Values span a broad range, starting by simple desires, wishes, and preferences and ending up with moral values as honesty, peace, democracy, and justice. By moralizing values ("This was a dirty trick!"), we take a turn from the expression of values to deontological validity claims. In his seminal "*Philosophie und Sprache*" (1937), philosopher Richard Hönigswald argued that such shift can be justified by means of discursive axiological language (see Ott and Surau-Ott 2017). The Neokantian background of Hönigswald allows him to make tighter connections between (supreme) values and morality than Habermas does. Following Hönigswald, a discourse ethical axiology must distinguish between *attribution* and *grounding*. Attribution means that agents attribute positive and negative values to entities and events. Grounding means that agents present and exchange *axiological reasons* why they attribute values as they do. This implies the distinction between expressive lingual articulation (attribution) and well-considered reflective value-judgements (grounding). Articulation is sincere, while grounding is considered. Grounding stipulates profoundness. To Neokantianism, grounding values was a transcendental enterprise ("Wertgeltung"). As we shall see with respect to environmental evaluation, axiological grounding differs from transcendental justification (Sect. 5).

In axiological grounding, reasoning may refer to substantial cultural traditions (as nature conservation), eudemonic experiences, phenomenological descriptions, psychoanalysis, narratives, history, and even literature and poetry. Axiological grounding does not necessarily have to refer to morals. It can be "deep" without touching morals. Phenomenology of nature (Böhme 2016) is helpful in grounding evaluations with respect to nature. Quite often, a reflective articulation presents sufficient grounding. If I say: "I strongly dislike this smell since it reminds me of vomiting in childhood", no further grounding is required (ceteris paribus). The bad memory counts as sufficient reason. We will return to the problem of axiological grounding throughout the following sections. To sum up the point we wish to make: *From an axiological perspective, valuation schemes should be conceived as to fulfil the requirement of allowing for both articulation and grounding*.

2.2 Economic Evaluation

Economics assumes that individuals make rational choices according to their preferences. Economic approaches being grounded in a concept of preference are paradigmatic to liberal individualism. A preference is a binary value-judgement ("To me, x is (ceteris paribus) better/worse than y"). An individual agent prefers a state X over Y according to her mental states. Reaching X gives utility (welfare) to the agent. The degree of preference is intensity. Behaviour reveals actual values people hold. Many, but not all values materialize in commodities (cars, mansions, books, carpets, jewellery, gardens etc.) which are relatively scarce and have an exchange value signalled by prices. One realizes values via consumption. Economic axiology is liberal, individualistic, flexible etc. Economists show respect for the many ways in which persons may value commodities, cultural events, and social affairs. Preferences are to count. Economics, however, is disinterested in grounding. It takes preferences as face values. Economists assume that people themselves know their real preference best, since they have privileged access to them. Ontogenetic origins, manipulation, advertisement, self-deceit, and indoctrination are abstracted away from economic models. Economics assume authenticity of all or most preferences and they ground their models on such heroic assumptions. To ethics, authenticity of values is an ideal, not a given. On a second-order layer, we all should wish that our important values are actually "ours" (Frankfurt 1971). Frankfurt defines this wish of having authentic preferences as "second-order preference". Disregarding such shortcomings, economists apply this axiological approach to nature, resulting in environmental economics and the TEV-scheme (Sect. 3) and even the ESS-scheme (Sect. 4).

2.3 Conceptual Clarifications

In the following, we are concerned with reflected evaluations (as opposed to ad hoc, spontaneous evaluations) or well-considered reflective value-judgements (grounding). In the first approximation, "evaluation" is understood as the attempt to gain a well-founded evaluation statement. In general, evaluations are carried out in order to establish or determine the (relative) goodness, value, quality, virtue, correctness or similar of the object of evaluation or the evaluandum (see Reinmuth for evaluation components in this volume). An evaluation should provide correctly substantiated, checkable and (at best) acceptable evaluation statements. Before the functions and roles of value systems in evaluations are clarified, a distinction is made between evaluation functions, reasons for and purposes of evaluation, and types of evaluations. In the literature, evaluations are assigned various functions (Döring and Bortz 2016; Lumer 1990; von der Pfordten 1993; Scriven 1999). One central function of evaluation is to express the evaluation result of a speaker and to show with evaluative reasoning that the value judgement is acceptable (and might be shared). In practice, an evaluation should fulfil different evaluation functions (e.g. cognitive, learning and dialogue, optimisation, decision-making and legitimisation functions) (Döring and Bortz 2016). Making claims for axiological validity supposes that values can be shared. Grounding values provides chances of values being shared.

Various reasons for evaluation can be identified, which can, for example, be institutionalised in professional areas: It can belong to certain professions, social roles or functions that one should or may judge, evaluate, value, examine, monitor, control, assess, grade, criticize, praise, appreciate, estimate, etc. These different evaluation contexts are accordingly associated with different expectations and specifications. Evaluations are often partial actions of action sequences—they are embedded in further action sequences and often provide premises in argumentations. If one would like to acquire a bicycle, then one will judge a suitable offer comparably and will justify on the basis of an evaluation statement the decision that this bicycle is to be bought. Professionals have expertise in valuing artefacts in economic terms, such as cars or real estates. Such assessment of economic value is independent from any preference of the professional.

As the evaluation motives can be diverse, different evaluation purposes can be pursued with evaluations. As was already mentioned, evaluation actions can be partial actions of further action sequences, which pursue in each case certain purposes. The specific purpose of (systematic) evaluations, to justify in particular evaluation propositions, emphasized above, is embedded accordingly into further sequences, whose purposes can be referred also in this wider sense to evaluations. Embedded into further action sequences evaluations serve the action orientation, coordination, guidance and justification and the improvement of operational sequences, objects, devices etc.

Different types of evaluations can be distinguished. The corresponding classifications can be based on the occasions for evaluations, the methods used, the ways in which the results are formulated, the openness to adaptations, etc. It is to be considered that different evaluation types fulfil different functions and can serve thereby different purposes. The difficulty of accurately characterising and delimiting grading, ranking, scoring, etc. can result from the fact that these expressions are sometimes used with reference to the results of an evaluation or the process of evaluation. Sometimes evaluation results are formulated qualitatively and sometimes quantitatively. Thus, marks or points can be assigned, the price can be indicated, or the evaluation result can be formulated with evaluative terms. Often scales are used. Depending on the scale type, different arithmetic operations and comparisons are permitted.

A distinction is to be made between axiology (values) and deontology/normativity (norms). Evaluations can be carried out normatively relative to norms ("According to environmental law, it is obligatory not to pollute waters") and axiologically relative to values ("According to strong sustainability, it is good to restore nature"). Norms include, among others, correctness statements, right-to-something statements and deontic statements (such as rules). Norms are instructions for action or can refer to instructions for action. Right-to-something statements or expressions such as 'correct' are normative, but not deontic, as they do not represent clear instructions for action (an act can be right if it is permitted or required, or if someone refrains from doing something that is prohibited). However, in one way or another they are related to deontic statements (like rules). For example, right-to-something statements can often be interpreted as rule clusters.

Axiological and normative expressions are evaluative expressions (Taylor 1961; von Wright 1963). Paradigmatic examples of axiological terms are 'good', 'bad', 'evil', 'super', 'successful', 'un−/just', 'suitable', 'reasonable' and so on. The term 'good' represents a language game of attributions, such as 'admirable', 'nice', 'awful', 'tasty', 'sexy', 'fancy', 'gorgeous' etc. Axiological expressions differ from deontic operators which prescribe or forbid different kind of actions. Deontic expressions and operators are, for example, 'required', 'ought', 'forbidden' and 'permitted'. Non-deontic but normative expressions are e.g. 'duty to', 'right to', 'in−/correct', 'right' and 'wrong'.

It can be argued that normative statements (e.g. norms and rules) are often formulated in order to summarise diverse axiological evaluations. According to such an understanding, norms play a central role because they act as a bridge between the axiological evaluations and normative evaluations (Baurmann et al. 2010). Norms are formulated because otherwise it is not clear which specific instructions for action are to be obtained from axiological statements. Norms summarize the efforts of an axiological evaluation—they formulate what should be done in view of the axiological considerations or prescribe the actions to be performed in view of the axiological considerations (or allow and forbid others). The bridge should be built between the axiological evaluation and the desire for clear specific guidelines for action. (Deontic) norms are (relatively) clear guidelines for action and via reasoning one can obtain individual norms which state what actions should be carried out by certain actors in certain situations. So, norms and rules can fulfil a bridging function. In formulating the norms, one tries to consider the various axiological evaluations as extensively as possible. Evaluations relative to values can be bundled by setting norms.

Besides that, there are statements about the quality of rules ("This is a just/good rule system") or the justification of rule uses ("It is good to set these rules"; "It is right to accept this rule system", "there should be a legal regulation"), or decisions to set rules in the light of values ("Let us do something about it!", "we must endeavour to ensure that there are rules for this"). Such statements and decisions mediate between evaluations and rules or norms (If X is good for us, we should act as to protect X). One could call them prescriptions or generic resolutions. From a speech act perspective, prescriptions are close to suggestions, recommendations, and ways of counselling. A prescription could state that there should be a legal regulation on the matter X (as oil spills, bycatch in fisheries, trophy hunting), but may remain silent on the specific deontic content of such environmental regulation. Grounded and shared values can constitute agreements that regulation is mandatory. Via such reasoning, the realms of axiology and deontology can be bridged discursively. So, prescriptions (in the sense of rule-setting decisions in consideration of axiological evaluations) build another important bridge. This bridge is between evaluations and actual implementation of the evaluative insights ("In view of our values, we should set the-and-the norms" or "In view of our values, something should be done urgently"). Evaluations are often based on our shared values or attitudes to our values. Evaluations can often motivate action. Prescriptions claim a need for regulation, but are not yet rules. They are assertions that X, having been so and evaluated, should also be regulated in some way ("We have to institutionalize a conservation law!", "We need protected area categories for marine nature conservation!"). Prescriptions, rules and specific deontological norms would then be specifications, until finally a specific doer P knows what to do in a certain situation. The difficulty, however, often lies in translating various evaluations into clear rules for action. The bridge between evaluations and the decision to change something is more on the motivational side. The bridge between values and clear instructions for action is more about the quality of norms.

Communities endorse shared values as they specify them to rules, rights, and commitments. Peace, liberty, health, safety, wealth, democracy, and decent environments are instances of "our" commonly shared moral values. Moral values require a generic betterness-relationship between two oppositional concepts: To all reasonable agents (prima facie and ceteris paribus) there is peace better than war, arguing better than violence, health better than maladies, wealth better than poverty etc. A non-polluted environment is better than a highly toxic one. In environmental valuation, however, such betterness-relations are full of vague qualifiers as "spoiled", "decent", "degraded", "rich and diverse", "impoverished", "original" etc. These qualifiers indicate that a broad and unspecific betterness-relation in favour of decent environmental conditions might be of moral value, while specifications remain culturally bounded (Sect. 6).

In any case, axiology operates within a range having a contested border zone to deontology/normativity (rightness). This borderline region between evaluations, moral values, ideals, obligations, and principles is highly contested even among ethicists.

After clarifying what is to be understood by the complex term "evaluation", the role of values in relation to *evaluations* can now be analysed. Values play a dual role in evaluations. First of all, they are central to all evaluations, as they guide the selection of criteria and standards and thus also the design and formulation of criteria. In order to fulfil the function of criteria design, one must be clear about one's own values and their strength (or intensity). If nature conservation is important to you and you attach a high value to biodiversity, then you will use appropriate criteria to evaluate interventions in nature. In view of the evaluation functions, in particular enabling decision making, formulating evaluation results is often attempted not only in evaluative terms, but to use "objective" numerical values for the supply of decision bases. Since various aspects of situations can be evaluated in different ways using different criteria, but clear decisions have to be made (e.g. laws have to be given), this way attempts to minimize complexity and to abstract away difficult questions. Many scholars wish to operationalize evaluations. The evaluation *that* X is of value to P remains vague if it is not specified to the question *how much value* does X have to P in relation to many other valuable entities and events. Such specification must homogenize and in economics there is no better homogenizer than money, as specified by willingness to pay (WTP). If a person P values X positively, her WTP should be greater than zero. The epistemic idea to operationalize values numerically in monetary terms deserves reflective scrutiny: May such operationalization open our eyes or may $-numbers blind us against the actual substances of values? How is numerical economic operationalization related to attributing and grounding? What axiological lessons can be drawn from contingent value studies of virtual WTP for nature conservation?

The second function of values is precisely to formulate evaluation results. Since we are talking about reflected evaluations here, one can assume that value statements are the result of well-founded evaluations. One can demand and give reasons for certain valuations and value systems. One can point to missing transparency of evaluations and doubtful consequences. Arguing about values and evaluations is possible. Values and valuations are related to philosophical underpinnings and frameworks. Valuations are associated with varieties of values and major philosophical questions. A philosophically informed analysis can help answer the question, which value systems can fulfil the purposes and deliver appropriate evaluations. As stated above, axiological discourse should give credit to the plurality of value encounters with respect to both attribution and grounding.

The result of this section implies, that all value-schemes should be aware about the deep axiological background within they operate. Environmental value schemes should be able to integrate axiological reflections on the ontology and epistemology of values, such as Weberian clashes of values, second-order preferences, the contested zone of moral values, the many axiological correlations, the role of prescriptions and the distinction between grounding and attribution. Such topics kept in mind, we turn to the evaluation of nature.

3 Total Economic Value

In environmental economics, the Total Economic Value of Nature (TEV) approach was proposed (see Randall 1987, Pearce and Moran 1994, Plottu and Plottu 2007, see also contributions in Kumar 2010). It is based on a preference-based axiology and embedded in micro-economic theory of rational choice. The intensity of the preferences is reflected in the willingness to pay (WTP) for nature conservation or in the willingness to accept (WTA) compensation for a loss of preferred nature. Interestingly, the concept of intensity forms an interface between economics, phenomenology and even morality (Ott 2013). Nature can be a source of both worth or values and the opposite of worth or disvalues like earthquakes, pests, infectious diseases, etc. Nature is not just good for humans. For the rest of the article, we keep the dimension of disvalues and disservices closely in mind but focus the benign and beneficial dimension of nature. Nature is conceived being a broad source of utility for humans and "utility" is a generic term for all kinds of benefits, welfare and pleasures that result from it. One can also use natural systems as source of resources and as sinks for pollutants. The "source-and-sink"-perspective is common in environmental economics.

This anthropocentric and preference-based TEV approach also distinguishes between use values and non-use values. Use values include, among others, yields (direct use) and tourist areas (indirect use), which can be measured in monetary terms by travel cost analysis.

Option value, bequest value and existence value are categories of non-use values within the TEV and refer to preferences in favour of nature conservation and protection. *Option values* refer to a preference to make decisions from a number of actual future options whose details are uncertain or unknown in the present. If tropical forests and the deep sea are regarded as natural "laboratories" in which many types of biochemical compounds are "tested" by the forces of evolution, humanity has reasonable grounds to preserve such environments for future food production, medical, pharmaceutical, or chemical research. Algae, for example, can have many options that are still unknown. Since humans are omnivores, option values are important for future food security. Perhaps an ecological civilization will shift cultural barriers against certain edible plants and insects. Whatever that may be, we should keep promising options open. Nature destruction can exclude options before they are identified. Option values of nature are dispositional ones. As such, they are hard to monetize. Ironically, there might be economic analogies between option values of nature and the speculative future value of a start-up company at the stock markets. Perhaps, licences for exploring some areas may indicate option values. There are many ways by which nature can be "optional" to humans. Genes, species, and even landscapes are full of options many yet unrealized. Restoring nature should also count as an option. Grounding option values oscillates between generic and specific options. The option value of the sea floor is highly generic, while the option value of some algae species can be specified in terms of food processing. Grounding option values presents specific dispositions of how the non-human world might become significant for human intentions.

Another axiologically interesting category within the TEV is *existence value*. A beloved person is a paradigm case for existence value. The existence value applies to natural entities when an agent evaluates the mere existence of a natural being N without further interest to utilize N. It is perfectly reasonable to say, “It is good to know that there are snow lizards in remote parts of Central Asia.” The existence of X is preferred over the non-existence of X. This preference may clash with the opposite evaluation of another person. To some people it would be better, if there were no wolves around, while some other people prefer the existence of wolves in a given area. Conflicts over existence of natural beings will prolong in conflicting prescriptions (regulations), such as licences for hunting wolves. It might be an instance of inconsistency if a person P gives positive existence value to an old tree, but gives negative existence value to its leaves in fall. Can P wish to have the tree without its leaves?

Existence values point to the diversity of landscape formations, such as coasts, mountains, lakes and units of cultural significance, etc. For many people, a garden with birds, butterflies, bees, spiders, dragonflies and bats is better than a garden with only a few abundant lawn species.

Existence values can be grounded in many reasonable ways. If a person would mourn over the loss of X and might miss X deeply in her life, she implicitly has given existence value to X. These ways of groundings indicate that Willingness to Accept (WTA) is a better measure for existence value than WTP. Grounding existence value touches the problem of *missing* something or missing somebody (dearly). The scheme “P missing X” gives grounding for existence. Who, however, misses species that have gone extinct? Does anybody miss virtual species which might have existed but have gone extinct before they have been identified by taxonomists? Probably, existence value is more about what environmentally well-informed persons *should* miss and what *should* count as loss. As many contingent value studies strongly indicate, the existence value is, to many persons, at odds with the ongoing extinction of many species. It does not even seem inappropriate to place an existence value even onto biodiversity as such. If the WTA or WTP for the protection of an endangered species were $1 per month, however, the existence value of biodiversity could devour all income and wealth (“embedding effect”). Despite this strange effect, it is perfectly reasonable to greatly appreciate a diverse natural world.

Nature’s existence values cannot be neglected in monetary terms either. Since affluent people in the North are putting high WTA values to the existence of tropical nature, including crocodiles, tigers, rhinos, etc., the progressive destruction looks repulsive from an economic point of view. WTA, however, remains virtual payment and does not mobilize real financial assets for protecting nature. There are many ideas how to make real incentives to protect nature out of virtual WTA.

Values of existence are often associated with the slogan “Use it or loose it”. The organization of high-end tourism to present the “Big 5” is much more rational than the deforestation of forests to produce charcoal. Tourism is an industry that has specialized in bringing wealthy people to places where they can realize existence values ("I really have seen a lion in the wild!"). When wealthy people accept high travel costs to experience X, X is economically very valuable. In the next section, we will review the parallels with the cultural services of ecosystems.

Option and existence values become *bequest values* when people want to preserve options and existence for future generations. We will show in Sect. 5 that this does not lay an adequate moral foundation for questions of intergenerational justice.

4 Ecosystem Service Approach

The Millennium Ecosystem Assessment Report introduced the concept of ecosystem services (ESS). It was adopted by the TEEB study (The Economics of Ecosystems and Biodiversity). This anthropocentric concept aims to bridge the gap between nature and human well-being and make the values of nature visible to decision-makers and the wider public. Prominent references are Costanza (2008), Daily et al. (2009), Norgaard (2010), Sagoff (2011), Kandziora et al. (2012), Davidson (2013), Chan et al. (2012), Jax et al. (2013) and Spangenberg et al. (2014).

ESS takes the form of a cascade ranging from nature to natural capital to a flow of services that offers benefits to people relative to the underlying values. ESS distinguishes between services and disservices of nature, but most ESS studies abstract disservices away. Disservices are for example pests, earthquakes, thunderstorms, heavy snow, but also sharks that kill people. Rain (although it is not produced by ecosystems) can be seen as a disservice for tourists, but as an important support service for farmers.

ESS wants to close the gap between nature and man. The ESS cascade begins with a concept in which nature is gradually transformed by human action. Nature is not just wilderness. Many managed ecosystems produce ecosystem services. Prudent management can increase the flow of some services, but such an increase often comes at the expense of other services. Thus, many ecosystem services originate from mediations between nature and human labour. The provision services of yields often require agriculture and gardening, even if there are some berries and mushrooms out in the wild.

One should distinguish between stocks and funds of natural capitals. Stocks, such as fossil fuels, can only be consumed away. Consumption diminishes the stock over time. Funds, however, have intrinsic properties to self-increase by proliferation and growth. There are non-living funds (as freshwater cycles) and living funds, such as organisms, species, populations, and ecosystems. Funds equal "renewable resources". The distinction between stocks and funds explains why it is false (non-sustainable) to treat funds as stocks. If funds are treated as being stocks, they are over-utilized. Both stocks and funds yield flows, but details of this fund-flow-correlation remain puzzling. A tree stores carbon (regulating service), it produces oxygen, timber and, perhaps, eatable fruits (provisioning service). If, however, the tree is appreciated as being beautiful, is there a series of pictures flowing from the tree to the eye of the beholder? Rather not. If oak trees symbolise my home county, what kind of flow might this be? Both examples indicate that the fund-flow-model does not work well with respect to the domain of cultural services. Cultural values are not flows, but are constituted by axiological-cultural perceptions, by attribution and grounding (Sect. 2). If so, we need models being more convincing on philosophical grounds (Sect. 5).

Moving further along the cascade, it is further assumed that humans are benefitted by such "flows". A service benefits some beneficiaries somehow. Without such benefit, some humans would be worse off. Thus, a service counts as "good". If so, it has positive value (benefit) to someone. To destroy such values, implies a loss or a damage being done to somebody else. This value is never isolated from other values but embedded in the entire horizon of values coming in multiple constellations and retreating into a deep background. Thus, the ESS cascade finally immerses into the entirety of cultural values being connected to prescriptions and, at least sometimes, to deontic terms. The ESS scheme mediates between the two abstract poles of nature and culture, overcoming a mere divide.

When using value systems, such as ESS, one should point out that one uses the term "service" as a purely technical term that is established in the sense of "ways in which nature can be useful to humans". Regretfully, the term "services" conveys misleading connotations. Nature does not offer services like a company does. We should not perceive nature in analogy to the service industries, but in its ecological naturalness and its fertility, resilience, diversity and abundance. The "service"-- terminology has become common parlance. Even if there are good reasons against such terminology (Kirchhoff 2018, 2019), we should not discard the terminology completely, but integrate the ESS-approach in a broader ethical framework.

The ESS approach distinguishes between *supporting*, *provisioning*, *regulating* and *cultural* services. Each category includes several subcategories. The category of supporting services is controversial. They are basic environmental requirements for services, but not services themselves. They are necessary preconditions for services without being services. Such supportive "services" are ecological functions and structures that sustain the totality of a particular ecosystem (sometimes referred to as "natural integrity"). Supporting services are "primary values", such as exergy, emergence of productivity and resilience, and fertility as generic disposition of living beings. Since supporting services may include double counting, some scientists abstract them away from the realm of real services. However, some important ecosystem services, such as pollination, are neither provisioning nor regulating or cultural services. If they belong to the category of supporting services, this category should not be fully abstracted away. We may put high existence value to top predators but should remind that ecological systems are running via the invisible support of small organisms.

Provisioning services refer to all species used by humans, including spices, cosmetics, pharmaceutics and medicines. Provisioning services run parallel to the TEV use values. These are mainly yields that can be measured both physically and in monetary terms. *Regulatory* services also belong, albeit rather indirectly, to the category of TEV use values. They can also be measured in physical terms and by economic replacement costs. A famous example from the Catskill Mountains close to New York city showed that the investment and supply costs for the purification of fresh water using technology were far higher than letting the mountain range do the job (Elliman and Berry 2007). Thus, the mountain range was preserved for its regulatory services on economic grounds. If reed can filter toxic substances from wastewater, it also performs a regulatory service. If the reed will be used to stow walls to secure heating energy, it also provides a supply service. Pollination by bees is far cheaper than by human labour. In this way, the ESS approach can open our eyes to innovative bioeconomic strategies for the multiplication of ecosystem services.

Cultural services are often underrepresented in ESS studies because they are difficult to quantify and monetise. The domain of cultural values encompasses aesthetic values, leisure and recreation, local design and natural heritage, meditation and transformation, and not least the spiritual and symbolic significance of nature. It is widely recognized in the literature, that cultural services are highly important to many people, but are underrated in many ESS studies. This is an axiological mismatch within ESS. As mentioned above, the stock-flow-model misrepresents the axiology of cultural services. Both mismatch and misrepresentation indicate that cultural values stand in need for a better ethical framework (Sect. 5). Kirchhoff has proposed to discard the "service" terminology and speak of nature's values instead (Kirchhoff 2018, 2019).

The ESS approach points to the many compromises and trade-offs between provisioning and cultural services in land use. There is a trade-off (conflict) between aquaculture and recreation in coastal zones, a trade-off between blooming meadows and intensive biomass production, a trade-off between rewetting bogs or peat extraction, a trade-off between habitats for endangered species and tourist destinations.

The ESS approach as such is silent on how such trade-offs are to be decided. ESS as such does not include a theory of decision-making, conflict resolution, or weighing goods. ESS can, however, identify cases, in which trade-offs are decided against the demands for nature conservation. There are reasons to believe that societal demand for nature conservation has, meanwhile, become higher in developed countries than its supply.

ESS, however, does not provide specific solutions to the interrelated problems of discounting, substitution and compensation. The problem of the marginal destruction of nature also remains unsolved in ESS. It points to the fact that nature can't be destroyed entirely, but is lost slow by slow and unit by unit. Cost-benefit analysis often come to the result that conversion at the margin is "efficient". It is silent on whether ecosystem services are equitably distributed among different social groups. The distributive justice of ecosystem services and global distributive justice among contemporaries in general opens up a broad field that goes beyond the scope of this article. ESS enables the functional substitution of ecosystem services. If a "service" is removed, such loss can be substituted by another service. Substitution of services faces limits in the domain of cultural services. Therefore, ESS, requires some additional ideas for the uniqueness of some natural sites ("de re"-protection). To sum up: ESS is not a comprehensive theory of nature conservation. It is rather a schematic tool than a theory. With some caveats ("flow", "service", "monetization") it fulfils the requirement to allow for attribution and grounding. Used in proper ways, ESS may be catalytic for environmental axiological discourse.

5 Value Systems in Environmental Ethics

Environmental ethics established classifying maps of values and ethical frameworks. After decades of discourse in environmental ethics, some essential (constitutive) ethical frameworks and value types can be identified and differentiated. These generic frameworks and value types have been mapped several times (Rolston 1988; Krebs 1999; Ott 2010; Muraca 2011; Ott et al. 2016). This section is based on these studies and pursues two concerns: It aims to distinguish five major value types and frameworks and to highlight the parallels between these patterns and categories of TEV and ESS. This opens many doors for further reflection on these categories.

5.1 Metabolic and Reliance Values

Human systems depend on and are embedded in natural systems that provide many different resources, goods and services. The direct use of nature for food and shelter is "metabolic" because, as Marx notes, all human societies depend on a continuous metabolism with nature. This general truth about man's dependence on nature is independent of technology and property rights. The categories "metabolic values" or "reliant values" are intended to cover this fundamental dependence. Dependence on nature differs depending on the spatial scale and degree of substitutability. Metabolism should be understood broadly. The metabolic values of nature have been mediated by human work, in particular by agriculture, animal husbandry, mining, forestry and fishing, including aquaculture. The extraction of oil, natural gas and coal provides fuels that are of instrumental value for many purposes. Breeding is a strategy to increase the instrumental values of cows, sheep, rice, and apple trees. The regular supply of fresh water, heating and cooking facilities to almost all members of society has taken many decades even in technologically advanced countries. In (post-)industrial and urbanized societies such dependence is often overlooked. Full supermarkets are simply a matter of course. Environmental ethics is critical against such forgetfulness and ignorance. This argumentation ("reliance values") has been linked to the environmentalism of the poor through concepts of decent livelihoods, especially in the Global South (Martinez-Alier 2002).

Humans have no alternative but to organise metabolism with nature. Social metabolism was intensified from the Neolithic to the great acceleration of the present age. Fundamental Neolithic achievements have paved a long way to the full-grown

Anthropocene. Such achievements were permanent settlements, agriculture, ploughs, networks, domestication and breeding techniques, storage, crafts and medicine. Modernity can be understood as a shift from qualitative services to increasing quantities (“more of the same”). It is a clever idea to catch fish via nets, but now the nets have become miles long and deep, catching the marine food web and influencing the development of fish species. As many narratives and figures indicate, the increased metabolism collapses into systematic plundering of our planet’s resources. The large-scale industrial metabolism with nature is exaggerated in many respects and for centuries has led to a huge raw material stock and a consumer culture (see Trentmann 2016).

Metabolic and dependency values are conceptually close to “utilization values” within TEV and close to provisioning and regulating services within ESS. The problem with TEV is that only factual preferences of individuals are recorded, regardless of whether these preferences are well informed or not, which can lead to underestimation of some ecosystem services. The entire cluster of reliance values, direct utility values, provisioning services etc. apparently just requires simple grounding in terms of (basic) needs, preferences, and demand. Utilization values can be conceived as being demand-driven. Such conception, however, may block a critical reflection upon current consumption patterns (in the Global North) and aspiration levels (in the Global South). TEV and ESS do not ask for proper attitudes with respect to the many “gifts” of nature, such as the attitudes of gratitude, frugality, and humility. Environmental ethics should stimulate the idea that grounding such metabolic reliance values should not be demand-driven but should become rather virtue-based (see end of this section).

The perspective of mainstream microeconomics can underestimate basic dependency values for methodological reasons, too. Economists can admit that primary goods such as oxygen, freshwater, fertile soil, photosynthesis, etc. are, as such, beyond price. The price of planet Earth is infinite, but the economic cost-benefit analysis evaluates local or regional changes at the margin. Thus, it is the method of marginal assessment itself which underrates nature. Therefore, metabolic values are dialectical as they shift between basic dependence on nature, marginal degradation, and substitution processes. Fresh water and fertile soils are paradigm examples for this peculiar dialectic. At the heart of this dialectics is the recognition that humans basically remain reliant upon nature even under recent conditions of almost perfect mastery of nature. Environmental ethics turns the economic perspective of primary values upside down: Each and any part of nature counts as being a parcel of primary values. The flip side of marginal increase in utility is the marginal loss of primary values. Such dialectics turns into the political economy of strong sustainability (Daly 1996).

5.2 Eudemonic Values

There is now widespread consensus that the distinction between instrumental and inherent value is not a dichotomy if instrumental values are embedded in a certain understanding of a mean-end-relation. Eudemonic values can be seen as another category of values that includes aesthetic, locational, restful, transformative, and spiritual encounters with nature. As Ott argued in many articles (e.g. Ott 2016b), reconciliation between man and nature within the paradigm of instrumental rationality will not succeed. Clever animals have only instrumental and at best prudential reasons to protect natural resources. Environmental ethics emphasizes the many ways in which humans are bestowed by nature with types of pleasure, joy, wonder, connectedness, and even bliss and reverence. Eudemonic values give a new perspective on how different people might, could and should shape their lives with and in nature. They refer to outdoor activities that people perform for their own sake, such as hiking, sailing, diving, climbing and even hunting. If you go on a hiking trail for the sake of hiking, you give this activity eudemonic value. Other examples of so-called "eudemonic" values include the beauty of nature, a (deeper) sense of home ("Heimat"), relaxation, joyful physical exercises, biophilic sensations and spiritual encounters with nature. Here nature reveals itself as an essential dimension of a good, flourishing and meaningful human life. Eugene Hargrove (1992), Allen Holland (2002), Angelika Krebs (1999), and Roger Scruton (2012) have also argued along these lines.

The area of eudemonic values resembles the category of cultural services within ESS and it includes the existential value of TEV. It should become clear that some eudemonic values (aesthetic, spiritual, symbolic) would not be sufficiently taken into account by existence values or cultural services. In any case, it is unclear how a spiritual understanding of nature as being "sacred" can be captured by the usual definition of existence value ("value to the mere existence of a natural being N without any further interest to utilize N"). This is also true for biophilic attitudes. With some likeliness, hegemonic concepts of modernity have oppressed biophilic dispositions, while an ecological civilization will liberate them anew. Eudemonic values make also clear that one could and should restore nature as a joyful focal practice (Borgmann 1984).

5.3 Future Ethics

In connection with questions of distributive justice and the necessary conditions for a good life, responsibility towards future generations with regard to metabolic and eudemonic values is important. Future ethics is about fair legacies at different levels. Most approaches are critical to the promise of a growth-oriented economy that future generations will be far better off than previous generations, as scarcity of commodities is reduced by GDP growth and technological innovation. Overabundance of commodities may coexist with increasing scarcity of nature's values. It seems uncertain whether future humans will simply conform to such situation. They might also deeply mourn the losses, some of which might be irreversible. Ethical approaches face different problems with future generations. A utilitarian approach to posterity must face the abhorrent conclusion that it would be better to increase the mere number of sentient beings as long as the worst beings still prefer to be alive rather than non-existent. A contractarian approach does not capture the convictions that we owe something to posterity, even though we cannot yet make contracts with future persons. If all obligations come from real contracts and contracts are concluded for rational self-interest, contractarian ethics cannot justify binding obligations between generations. Paradoxes of future ethics consist in bringing individuals into existence and controlling population size.

For questions of future ethics, the option value and the bequest value of TEV as well as all service categories of ESS are taken into account. Within TEV, however, the bequest value is nothing more than an altruistic preference that one may or may not feel for one's descendants or for distant future human beings. To economists, saving something for others is a kind of sacrifice. Bequest values are comparable to those of donorship. From natural inclination, the bequest values are mainly dedicated to the offspring, while morality also requires concern for distant and remote future human beings. Within a preference-based approach, it must be accepted that the bequest values decrease with increasing distance in time and space (as is often the case). TEV-scheme cannot see the moral difference between contingent altruistic preferences and mandatory obligations to future generations. Being morally obliged to do x is different from doing x out of an altruistic preference. The resulting action may be the same, but the reasons are different. Ethicists will not like to base future ethics solely on altruistic preferences. If so, TEV is not a suitable framework for intergenerational justice. If so, we need to transform the category of bequest value into a more refined and comprehensive ethical framework, recognizing rights of future persons against present persons (Unnerstall 1999).

The moral beliefs behind the "bequest value" of TEV require a deontological interpretation of future ethics. If the chain of generations implies a fundamental egalitarianism between generations (no generation is "better" than any other), then one can assume that future generations should have approximately the same living conditions as today's generations. If all people were equal in the present, the standard of comparison would be easy to determine. Since humans are, at present, highly unequal in many respects (salaries, wealth, education), it is almost impossible to apply a comparative standard on a global scale. At the global level, one should rather adopt an absolute standard, which is a moral threshold for a worthy human life, however it is specified in terms of needs, welfare, or capabilities.

At a particular level, however, political communities (states, nations) can and should pursue the strategy of bequeathing legacies to future members of a particular state on a comparative basis. They should protect the nature capitals and the natural heritage on their national territory. The conservation, preservation and restoration of nature is never entirely "universal" or "global", but must remain a special and "located" enterprise. Grounding nature's values touches the problem of specific territories which are inhabited by specific people. Inhabitation is full of values ("place making", "coiling the land") which might be shared by particular communities but can't be as universal as moral rules. Grounding values in specific territories reveals that territories are not just neutral space. Inhabitation values, if grounded, may conflict with cosmopolitan values.

A conflict-laden dialectic takes place here. If intergenerational justice to an absolute standard cannot be limited to future people and should not be ignorant against current poverty and misery, and if some states can ensure a high comparative environmental standard exclusively for their own present and future populations, then the demands of morality and global justice will inevitably exert high pressure on such comparative standards as being "privileges". From the moral point of view, the universal absolute standard seems to override certain comparative standards being enjoyed by some, but not all people. The future world might be highly patchy in terms of nature conservation. Some people will enjoy the results of success stories in nature conservation, while other people have to face results of environmental destruction. On which grounds are the few happy wealthy Norwegians entitled to enjoy their sublime landscape in a world full of slums? Such moral dialectic also points to immigration policy, for wealthy states that pursue ambitious environmental (and social) policies will become attractive destinations for migrants.

The moral tension between absolute and comparative standards makes a brief meta-ethical reflection on the problem of overridingness and a presumed hierarchy of reasons mandatory. Should specific moral reasons to help poor people always "trump" all other kinds of reasons, be they based in values, traditions, loyalties, role obligations, prescriptions, cost estimates, nature conservation objectives etc.? Are moral reasons to be embedded in other kinds of practical reasons or are moral reasons always to be placed at the very top of a hierarchy of reasons? Embedding moral reasons, however, will bring different results with respect to nature conservation than a supremacy of moral reasons. Just think of curtailing human entitlements in order to safe species from extinction, restrict access to protected areas, or enhance local biodiversity via reforestation at the expense of agriculture. Both TEV and ESS are too schematic to address such peculiar and highly political casuistry.

5.4 Inherent Moral Value

One major approach to environmental philosophy looks for the "right" solution to the demarcation problem and bases its obligations and virtues on this solution. The problem of demarcation concerns the question of how to draw the line between morally considerable beings and other entities or to put it otherwise: which entities have intrinsic (or inherent) moral value and which have instrumental (functional, economic) or eudemonic value. Another approach is environmental pragmatism, as presented by Bryan Norton (2005). Environmental pragmatism is embedded in the democratic-reformist philosophy of pragmatism (Dewey), it lets itself be convinced by valid argumentations, it is based on ideas about strong sustainability, it is liberally pluralistic with respect to the values of nature, and it pleads for profound reforms in our practical dealings with nature. The first approach is (too) monistic and focuses on the demarcation problem as the core of environmental ethics. We consider environmental pragmatism to be the most plausible framework for debating value systems and other environmental ethical issues. Nonetheless, discussions about inherent moral values as attributed to natural beings are very important (see Ott 2008).

The monistic search for solutions by prominent environmental ethicists is misguided because crucial moral concepts and values are essentially controversial. It is not promising to wait for the "right" solution of the demarcation problem, from which all rules for conservation and restoration should be derived. It is a hindrance to hope for *the* only true solution to the problem, which entities are inherently morally valuable (= determine the extent of the moral community), and then to derive a theory of conservation. Moral problems must be solved as well as other problems. If a problem is a real problem, solutions must be within reach—and so must moral problems. However, if an idea or concept is substantially challenged, there will be no final solution. The demarcation problem seems to be an essentially controversial search for a "true" solution.

The extent of the solutions to the problem of demarcation put forward so far can be determined as follows: (a) sentimentality, (b) zoo-centrism, (c) biocentrism, (d) eco-centrism, (e) gene-based approaches, (f) (pluralistic) holism. As Ott has argued elsewhere (Ott 2008), the demarcation problem requires the identification of morally relevant characteristics (properties) attributed to natural beings. In this way, one will not fall victim to the naturalistic fallacy. Candidates for morally relevant traits are sentience, communication skills (Ott 2015) and openness to a world "outside". The (gradual) ability to communicate deserves special attention (Hendlin and Ott 2016). One has long underestimated the ability to communicate within nature, and has wrongly silenced nature. In nature, however, there is both noise and voice. If animals can give a voice to their mental state, we can and should interpret such voices and translate them, as advocates, into human discourse.

Most scholars would attribute inherent moral values to sentient creatures. If inherent moral values are based on the assumption of morally relevant attributes and the most relevant attributes (sensation, communication) are gradual, then it might be permissible to graduate inherent moral values. We should better not homogenize morally relevant traits. The concept of equality could trigger the errors of homogenization of natural beings with morally relevant traits. The principle of equal consideration of each individual sentient member of the moral community makes grading possible. The survival strategies of mice, frogs, turtles, etc. as such (so called "r-selection") place hardly any value to the individual. This is of some relevance of how we should value such r-species individuals. The moral standpoint does not require all small wild sentient animals to be protected from suffering and premature death (Horta 2017). Egalitarian animal welfare activism and the idea of "policing" wild food webs exaggerate sentientism in an absurd way. The egalitarian animal rights movement is completely reversing the way humans have treated animals since the Neolithic Revolution. It is an absurd demand that man should strive to reduce the pain of prey in terrestrial and even marine systems and ideally transform wild nature into a gigantic zoo. An egalitarian sentientism loses contact with human practices such as domestication, animal husbandry, gardening and hunting. It cultivates, however, the practice of pet keeping and it gives political rights to pets ("Zoopolis", Donaldson and Kymlicka 2011). Policing wild nature, granting political rights to pets, and abolition of hunting and domestication present a somewhat weird result of animal rights theory. The result looks weird because it runs counter to how humans interacted with animals since they left the stage of hunters and gatherers.

Equity is a gradual alternative to equality. Equity means adequacy to the degree to which morally relevant abilities are actually present in a natural being. The faculty to sentience should be coupled with the ability to communicate under the principle of equity. Plants do not communicate with each other, but they transmit signals that are decoded by other plants in the environment. This differs from the gestures with which dogs interact, and such interactions differ from a linguistic interaction between a chimpanzee and a human being. A discursive being would therefore not be equated with a capacity to exchange information on biochemical signals. A principle of equity, joined with the combined criteria of sensitivity, communication and biological strategies, can provide a solid basis for gradually overcoming anthropocentrism, which is in reflective equilibrium with common intuitions about what we owe non-human beings.

This entire pattern of reasoning about inherent moral value goes beyond TEV and ESS. However, most TEV and ESS scholars acknowledge that the Inherent-Value-Problem should be taken seriously. Within the TEV, however, it holds that if all people believe that Anopheles mosquitoes are worthless, there is no reason to protect them. If WTP is zero or less than zero, there are reasons to remove such parts of nature. Only if people want to see penguins or observe whales, there is a reason to protect these animals. In the case of whaling, however, economists would try to maximize the net present value of whale watching tourism and whale hunting for trade. Rich Norwegians may sometimes like to watch whales, but they also enjoy whale meat in some expensive Oslo restaurants—and they will pay for both. The efficient solution would be to protect the whale populations that live near tourist destinations and kill whales in remote parts of the ocean for luxury food with a fancy smell of decadence. This solution seems clearly cynical to conservationists who may give inherent moral values to whales. To sum up: the problem of inherent moral value in nature can't properly addresses within TEV and ESS. Since it should count as real moral problem, environmental ethics can't be reduced to TEV and ESS.

5.5 Conceptions of and Attitudes Towards Nature

The considerations so far in this section illustrate how diversely nature is valued and how reluctant one should be in view of one's own ignorance to make conclusive and unambiguous evaluations. This is the reason for the fifth set of issues concerning conceptions of and attitudes towards nature. Within environmental ethics we find approaches based on a *non-scientific concept of nature*. Here nature is conceived as something other than a collection of mere objects that fall under general laws of nature. Many thought patterns within contemporary environmental ethics take a critical attitude towards a "purely scientific" interpretation of nature. In this interpretation, nature is nothing more than (a) the subject of scientific description and explanation, (b) a warehouse of resources that can serve as an entrance into industrial production, and (c) a hostile force against human longing for safety, health, and comfort. Within environmental virtues ethics, it is accepted that certain attitudes to and perceptions of nature are morally more appropriate than others. A general attitude of dominance, mastery and control can be rejected for moral reasons, and certain views of nature neglect morally relevant qualities or are morally subcomplex. The idea of deep ecology, as conceived by Arne Naess, was to sidestep modern ontology and replace it with "ecosophies". Ecosophies are not in direct competition with science. Ecosophies only assume that nature can show itself in its naturalness in modes and ways beyond scientific observation, data mining, and causal explanation. These ecosophies may have one thing in common: nature reveals itself in different forms in different places for open-minded people. Nature shows up (eventfully) as "physis", "creation", "kosmos", "dao", "wild" or "pacha". ESS can address such revealing of nature within the category of spiritual values, being a sub-category of cultural values. ESS must hold contact with religious studies. Here, monetization clashes with the logic of the sacred. This logic is not just about strict protection of sacred sites and sacred groves, but goes beyond if entire ways of lives are seen in perpetual spiritual encounter with ancestors, spirits and deities of land and sea. Seen from the category of spiritual cultural values, the entire ESS and TEV schemes look "Western". The ongoing conceptual debate within IPBES is about Western biases within ESS and TEV.

Environmental virtue ethics requires an appropriate attitude towards oneself, others, time, and natural beings. Environmental virtues ethics evaluates arbitrary characteristics of individual character and bases environmental virtues on moral arguments. The virtue of sufficiency is based on resistance to the consumerist excessiveness of human metabolism. Many (biophilic) virtues are based on eudemonic values. Eudemonic values can have a transformative force, as Bryan Norton argued (1988). Environmental virtue ethics demands with a future ethical impact the prudential virtues of restraint and care, foresight and precaution. It also means being aware of finiteness and mortality, since the earth belongs to the living in usufruct (Thomas Jefferson). It can also justify the existential attitude of reverence for life, located at the interface between biophilia and biocentrism. Values, virtues, and moral obligations are often expressed in narratives, nature essays, proverbs, chants, and consultative citizen juries. There are valid meta-ethical arguments why not only voices in environmental discourse should be considered that meet Western standards of logical thinking. Eye-opening modes of linguistic articulation, including "thick" phenomenological descriptions, can change attitudes towards natural beings, including landscapes, and sensitize one to the many values of nature. After all, environmental virtues can trigger new maxims such as "leave no trace". Eudemonic-cultural values, strong sustainability and the gradual overcoming of anthropocentrism should shape one's own set of environmental virtues. The spiral-shaped combination of eudemonic-cultural values, strong sustainability, environmental virtues ethics and the recognition of unscientific, spiritual encounters with nature could be described as "deep anthropocentrism", being augmented by some reasonable solution of the demarcation problem. Both TEV and ESS abstract away the problem of virtues, but grounding existence value, cultural services, and bequest value has to remove such abstraction.

6 Synthesis of Approaches: Between Cynicism and Sentimentality

In this final section, the briefly presented value systems are examined under philosophical guidance. In particular, we will highlight the strengths and weaknesses of the ESS and TEV with respect to axiological discourse about environmental evaluations.

In the first instance, TEV and ESS open eyes for values and services of nature which are hard to ignore by policy-makers. ESS values can be combined with TEV values: The combination of provisioning services (ESS) with option value (TEV) gives reason to conserve genes "in situ" (or as second-best solution in seed banks). In such ways, ESS and TEV can enrich and refine the ethical pattern of arguments. TEV and ESS can determine through opinion polls how groups of people actually benefit from natural capital, and they can say this in the language of preferences, interests, trade-offs and opportunity costs. Such parlance is "lingua Franca" in our commercialized world. TEV and ESS can also point to the many trade-offs in human-nature interactions. Both TEV and ESS can be useful schematic tools designed to make the values of nature visible to people with economic mindsets. However, people who use these TEV and ESS tools should realize that such tools can also conceal and hide deeper philosophical problems if they are regarded as ultimate ethical wisdom. Deeper philosophical problems, such as (a) attribution and grounding of evaluations, (b) the demarcation problem, (c) problems of distributive environmental justice (comparative and absolute standard), (d) the problem of virtuous attitudes towards nature are neither resolved by TEV nor by ESS. Both TEV and ESS point to the interfaces between environmental ethics and environmental economics. Environmental ethics can and should learn from economic theory (and vice versa). Debates at the interfaces are about discounting, compensation, replacement costs, replacement of functions and ("de re") uniqueness of some special natural monuments (such as Grand Canyon, Wadden Sea, Great Barrier Reef, Hardanger Vidda, Ladakalnis and others). The TEV categories "option value" and "existence value" can and should be implemented in the ethical argumentation patterns. The existence value falls into the category of eudemonic values and also touches on the virtue-ethical question of what kind of person one wants to be. In reflection, a preference for existence of natural beings opens a path of deep questioning (*sensu* Naess) about being human in a natural world. On reflection, however, one may cast doubts on the idea that mere existence as such can be of value. If a person wishes to ground an attribution of existence value to a natural entity, such grounding must go beyond the statement "X exists". Why would I miss X? Grounding existence value must refer to cultural heritage, beauty, transformative value, widening identification etc. If so "existence value" functions as a turn-table ("Drehscheibe"): It is an outer frontier to economics but also an entrance doorway to environmental ethics.

The same applies to the category of option value, which falls within the pattern of future ethics. The options should not only refer to future resources, but also include future options for people who want to liberate their biophilic dispositions and live as naturalists. Nature can be "optional" in many respects, as in eudemonic options. A logical analysis of modes of dispositions in nature is still missing. Such analysis might be a common focal research point for logicians and environmental philosophers.

One can ask TEV and ESS how the abstraction of the inherent moral value within ESS and TEV can be overcome. Might the category of existence value include a gradually overcoming anthropocentrism or is the existence value entirely determined by a preference-based mode of thinking? We see existence value as categorically different from inherent moral value with no conceptual linkage in between. The demarcation problem is not substitutable by existence value, spiritual encounter, strong reliance, and intense beauty. Grounding the demarcation problem quests for morally relevant properties of non-human beings, such as sentience and faculties to communicate. If such faculties come in degrees, gradual sentientism may count as proper solution to the demarcation problem, opening a contested casuistry.

ESS and TEV make the values of nature visible, but they do so for different eyes. The quantification and monetarisation of instrumental values not only highlights the ecological value of nature, but also provides information for market-oriented companies. Economic visibility is dialectical in itself. Economically, it cannot be denied that natural sink capacities (atmosphere, ocean) have become scarce. The increasing scarcity of ecosystem services is considered a loss. In many regions, fertile land and freshwater resources have become critically scarce. ESS and TEV can make people aware that nature has become scarce in many respects. If values change, the demand for nature can increase. If so, holders of natural assets profit. In order to achieve a new balance between supply and demand, enormous investments in nature capitals could be necessary. Ecologically, such investments should be designed in terms of ecological restoration.

Recognition of the scarcity of nature also provokes clever strategies in the real economy, including investment brokers, portfolio designers, developers and business consortia, to acquire scarce natural resources through property rights ("assets") and mobilize the return on investments and payments accordingly. Recognition of the scarcity of nature can draw attention either to issues of conservation, restoration and distributive justice (however specified) or to rational, interest-based private strategies to acquire scarce natural resources (land, water rights, concessions, quotas). The business perspective implicitly recognizes the collective scarcity of valuable nature but wants to use ESS privately.

The economic perspectives on the scarcity of nature often become an entrepreneurial perspective: How can entrepreneurs profit from ecological services? How can business models be designed accordingly? How can payments be initiated and managed? Once you have made the scarcity of nature visible, it is difficult to avoid such selfish business prospects for natural values. The large-scale acquisition of land ("land grabbing") is a paradigm case, but one can also think of the acquisition of concessions for timber and fishing, the acquisition of CO_2 credits, the acquisition of beautiful places as travel destinations and the like. Such acquisition strategies can affect local livelihoods, as a broad NGO discourse shows. They can distribute the benefits of ESS according to the given unequal patterns of purchasing power. Not surprisingly, egalitarian concepts of distributive environmental justice often reject TEV or ESS because of associated business models. Many people dislike the ideas that one may make a profit out of the conservation of nature or that nature's values are traded on markets. Market-based solutions and business-models count as corruption of the "spirit" of nature conservation. Market-based acquisition of ESS is either unfair or corrupt (or both).

However, not all businesses are morally wrong. Why should we completely deny that there could be morally decent ways to make some money with TEV or ESS? Beautiful campsites on Swedish lakes can mobilise the willingness of stressed-out Germans to pay to relax in such an open-air hut. Farmers might specialize in producing agroecological services beyond yields. The same holds for forestry. Why not pay some entrance fee for a land art park presenting sculptures in landscapes (as close to Vilnius)? In many cases the fundamental criticism against the monetarisation of nature can be misplaced. If so, we need a refined view of the business models and rights to open access. Free access to forests, beaches and lakes should counteract the commercialisation of nature. Perhaps different political cultures can solve this problem of the commercialisation of TEV or ESS in different ways. In the USA there is a fee to get permission to enter national parks, in Germany and Scandinavia there is Open Access.

In view of its internal dialectic of monetarisation of TEV or ESS, the economy can and should take the plunge into critical political environmental economy. To do this, economists would have to think about the scarcity of nature in close connection with environmental ethics, distributive justice and sustainability science. The economic visibility of the scarcity of nature requires economic-ethical disputes over property rights, access and business models, since distributive justice can demand free and equal access to beaches, forests, public parks and the like. However, the TEV or ESS approach as such is not necessarily a neoliberal, slippery slope towards the complete commodification of nature. A deep anthropocentrism can, with some limitations, adopt TEV and ESS as tools and measures that make the values of nature visible to economic and political actors and institutions. It is inevitable that they will do so for business models, but environmental ethics should not be afraid of new forms of bio-economy and entrepreneurship. The left-wing jargon against "neoliberal commodification" can also hide the potential for transitions within environmental entrepreneurship, "green" investments and corporate restructuring. If production of ESS would be profitable, ESS might be less scarce in the future. If so, there might be democratising “trickle down” effects of ESS. We leave the dialectics of exclusion (property rights) and access (liberty rights) to the rule of democratic governance schemes.

Cultural values overlap strongly with the so-called eudemonic values in environmental ethics (Sect. 5). From an economic perspective, the economic value of such cultural services must be measured through travel cost analysis, combined tourism analysis or contingent valuation, with WTP and WTA receiving virtual price tags. Cautious economists acknowledge the limitations of such economic instruments. Despite these limitations, they can provide useful information to stakeholders and policy makers. If a contingent valuation study shows that most tourists do not like noise on the beach, a destination becomes financially more valuable if noisy vehicles are banned by local authorities. An opinion poll can be conducted on whether projects affect cultural services. Do offshore windmills affect the beauty of the ocean horizon as perceived by tourists? Such an opinion poll provides quantified results. This method is a (snapshot) axiological opinion poll.

Such methods, however, remain at the surface of cultural values. In relation to deeper layers of cultural services, other approaches such as cultural history, landscape painting, conservation history, cultural anthropology, religious studies, etc. can contribute to a deeper understanding of cultural services being grounded eudemonic values.

The spiritual values of sacred sites as such remain obscure and opaque to scientific and economic methods. Perhaps only phenomenological expressions, such as atmospheres, auras and sacred sites, can be perceived by sensitive embodied spirits and how they form specific moods that come close to such spiritual encounters with nature. It is fair to say that cultural services must go beyond the epistemic idea of monetary operationalization. If the appreciation of nature as such goes beyond interest, it is simply misleading to ask for WTP. When people become radically open to special places (“genius loci”), it becomes pointless to ask for opportunity costs to replace them with shopping centres. However, for methodological reasons, ESS should be warned against undervaluing cultural services that cannot be monetised or physically measured (“How many tons of beauty?”). Many scientists fill the gaps of the ESS approach with ideas of participation, stakeholder involvement and conscious decision making.

The search for quantification is based on the ideal of operationalization and on the desire to homogenize the multitude of heterogeneous environmental values. Numbers simplify, but both ESS and TEV have intrinsic reasons to withstand simplification. If ESS and TEV are seen as derived instruments, close contact should be maintained with environmental ethics, enabling mutual learning. However, when TEV and ESS are overstipulated, they become victims of simplifications, are biased by their own abstractions and can serve economic interests in the acquisition of natural resources. In order to make convincing judgments, ethical reflection should take precedence over schematic tools. As we have argued in Sect. 2, evaluations can be argued with respect both to attribution and grounding. Grounding evaluations of natural entities is at the core of environmental axiology (Sect. 5). TEV and ESS are not well-suited for grounding as far as they are preference-based. It is sufficient to state or reveal a preference and declare some WTP or WTA. Such preference-based approaches may disconnect us from a deeper sense of valuing nature—and sharing such grounded values. Preference-based approaches are not wrong, but they obscure the profoundness of axiological life.

The two functions of value systems (Sect. 2) are to be considered in their fulfilment. While value systems such as TEV or ESS can be useful for establishing evaluation standards, values play a second important role in evaluations—as we have seen, value statements can be the result of reasoned evaluations. Axiological grounding of goodness in nature is different from truth claims, moral claims, and sincere expressions of sentiments. Grounding value judgements is an immersion into the cultural lifeworld, not just making explicit a contingent mental state. Grounding values means to adopt a commitment to care for something being shared as being "good". Can TEV and ESS be transformed toward such grounding? Yes, in principle, they can. As we argued at the end of Sect. 4, TEV and ESS can become catalytic for environmental ethical discourse, as presented in Sect. 5.

The choice and design of value systems is not a matter of arbitrariness. One can discuss and point out if certain value systems do not agree with other convictions. On the basis of evaluations, we can make well-founded valuations. Values also flow into economic valuations, since these are also the result of reflected evaluations. You want to know the price before you decide for it. But normally you don't just want to know the price, you also want to know if something is good. Practical considerations can speak for the choice of economic value systems, as these are operationalised, but the suppression of ethical value systems should not be done per se, as ethical beliefs are an integral part of our ways of life and judgements should be in a reflective equilibrium with our other beliefs. In order for value systems to perform their functions, they must help set the standards that we want to use—where we arrive at evaluation results that are consistent with our intuitions and where we know that we are valuing something for the best reasons. We raised doubts about the fit between TEV and ESS and our moral intuitions and about an unreflected use of these schemes. We should neither be cynics nor sentimentalists in the use of value systems. To support an informed choice of a value system, we should design value systems (schemes, concepts) being open for grounding evaluations.

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Environmental Indicators and Biodiversity Conservation Strategies

Carsten Hobohm

Abstract Humans have always observed their natural surroundings and used signals from the environment—environmental indicators—for survival and wellbeing. This publication provides an overview of the current discussion on environmental indicators, and the way it intersects with biodiversity policy and management at different spatial scales. It considers questions such as what is the meaning of environmental indicators related to biodiversity and ecosystems? How informative are different indicators? How may an environmental indicator help to find solutions for the use and management of ecosystems and the survival of the species it supports?

What current concepts, strategies and measures exist to protect the biodiversity and ecosystems? How effective are these with respect to observation, indication, control, legislation, effectiveness of policies and investment?

The simplest environmental indicators are single measurements such as temperature or sea level. Others are more complex and combine different factors, e.g. to describe the overall sustainability of a country or the so-called *ecological footprint* of a person. Nevertheless, even if the calculation behind an indicator is complex, the message can be communicated simply e.g. in a symbol such as red, yellow or green traffic light for action.

Some indicators that can be used to interpret environmental conditions, e.g. the *World Happiness Index*, are only indirectly related to the environment and focus mainly on social aspects and human wellbeing. Others are directly linked to biodiversity such as the *Living Planet Index* or *Red Lists* of threatened species.

It is impossible to protect all species on Earth in an equal manner or to accept the status quo as it is now. Based on the assumption that there is a general agreement to protect biodiversity as a whole on Earth, there are many different conservation concepts currently being discussed, developed and applied. This contribution reviews and evaluates some of the most important ones from a global perspective.

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The *no species loss strategy*, the *Biodiversity Hotspot strategy* and *ecological triage* are concepts that each integrate more than a single strategy or measure.

Payments for Ecosystem Services (PES) and *Biodiversity Offset Programmes* (BOPs) are recent schemes linking development programmes with payments for the restoration of environmental conditions and biodiversity. With respect to the number of annual publications and the amount of money invested, these measures seem to be of increasing interest. However, the programmes are often used/misused to enable and to support the development of buildings, infrastructure and industry. Thus, the value of such investments for the environment and biodiversity is rather ambiguous at the moment.

National Parks and *other types of protected areas, zero human influence strategies* and *wilderness, restoration measures, eradication of invasive species, activities against hunting and trade* of rare and threatened species, *captive breeding* and *release into the wilderness* and *de-extinction* comprise multiple specific measures and treatments which are currently being developed and used to protect the biodiversity and ecosystem functions.

Recent trends suggest that the amount of money invested for restoration measures, activities of zoos and botanical gardens, captive breeding, release of threatened species in the wild, and special nature conservation programmes related to certain threatened species will increase in the future.

However, at the moment it is questionable if other tendencies such as the increase in the illegal trade of species and natural products can be limited by stronger regulation and enforcement, or if other measures might be more effective.

Keywords Red list · No species loss · Biodiversity hotspot · Ecological triage · Offset and net gain strategy · Zero human influence · Habitat restoration · Eradication of invasive species · Illegal hunting and trafficking · Captive breeding · De-extinction

1 Introduction

Humans have always observed and interpreted their environment for nutrition, health, and survival. At all times, resource use in the landscape has been both dangerous and attractive. Thus, it is unlikely that there has been a historical period when humans have lived in harmony with their surroundings. The relationship between indication of environmental conditions, sensitivity and reaction in humans, animals and plants, i.e. adaptation, migration, learning, and so on, in general mirrors the interplay of positive, neutral and negative effects from the outside and inside of organisms and communities (Burt 1892; Basti 2012).

Environmental indicators are numbers, values, items, signals, results of measurements, or symbols that translate environmental data into a message. State indicators focus on the state of the environment. Trend indicators focus on timelines and change.

Recent frameworks of environmental indicator systems are e.g. the Pressure-State-Response model of the OECD and the DPSIR model (drivers, pressures, state, impact, response) of the European Environment Agency (Smeets and Wetering 1999). Appropriate ecological indicators can tell much about ecological conditions such as water quality, air pollution or nutrient availability of soils. Environmental key indicators according to the OECD (OECD 2008) are related to climate change, ozone layer, air quality, waste generation, freshwater quality, freshwater resources, forest resources, fish resources, energy resources, and biodiversity.

An optimal indicator should

1. easily be calculated, and the user should know how it is calculated or measured (simplicity),
2. the indication should be explicit (accuracy),
3. and discover a relationship which was not visible before (information). For example, we do not need presence-absence data of bird species like a curlew as bioindicator for wetlands or a vascular plant indicating urbanity as it is obviously easier to look at the type of a landscape or settlement than to identify a bird or vascular plant species with help of a scientific book, binoculars or a magnifying glass.

Furthermore,

4. the indicator should help to evaluate trends and to decide for action (announcement), and last but not least
5. the indication/measurement should be cost-efficient (efficiency).

In the following, the meaning of various environmental indicators with respect to what they can tell about ecosystem functions, the pressure on biodiversity or threatened species, and the success of nature conservation programmes will be discussed. This contribution reviews, compares and evaluates different concepts, strategies and measures to protect the species diversity on Earth under changing environmental conditions and increasing pressure on almost all natural and semi-natural ecosystems. There is an important feedback and interplay between the development and improvement of environmental indicators and measures related to ecosystems and biota.

2 Characteristics and Application of Environmental Indicators

Table 1 represents a selection of environmental indicators with a moderate to strong focus on the state and change of the biosphere, ecosystem and/or biodiversity. Some of the indicators are simple and related to a single factor such as mean temperature or sea level, others are a combination of two or more factors (like most of the

Table 1 Selected environmental indicators (in chronological order, according to the first use or publication)

Environmental indicator	Measurement and indication	References
Growth, well-being, and death of organisms	Observation of continuity and change in the environment	Basti (2012)
Temperature, global warming	Direct measurement of air temperature continuously since c. 1880 in certain regions: Air temperature at 2 m above the ground and water temperature at the surface of the sea, respectively; reconstruction of former temperatures for many millions of years and certain regions by different reconstruction methods.	IPCC (2014), Von Storch et al. (2009)
Mean Sea Level (MSL)	Direct measurement since c. 1880, reconstruction of former sea levels with respect to fossil and historical coastline indicators for many thousands of years regionally possible	IPCC (2014); other references see text
Biodiversity	Various calculation modes have been introduced to describe aspects of genetic diversity, species diversity or diversity of habitats per unit area	Arrhenius (1921), Gaston (2000), Hobohm (2000)
Bioindicators	Living organisms indicate different aspects of the environment, e.g. chemical or physical quality of the water, soil, or air. Scientific use and analysis of the sensitivity of diverse organisms	Kolkwitz and Marsson (1908), Klein (2008), Barinova (2017)
IUCN Red List of Threatened Species	The most comprehensive global inventory of threatened species including an assessment of the threats and conservation status of species; continuously updated since 1964	www.iucnredlist.org
Ellenberg Indicator Values (EIV)	Indication e.g. of soil characteristics such as pH, moisture and productivity by vascular plant composition	Ellenberg et al. (1991), Mountford et al. (1999), De Caceres et al. (2010)
Ecological Footprint	Hypothetical human demand on nature, i.e. quantity of area needed for production of food and material, absorption of carbon dioxide, traffic, construction of buildings etc., calculation of the indicator since 1992	Borucke et al. (2013)
Living Planet Index (LPI)	Observation and assessment of 2991 species and 15,000 population trends worldwide	World Wide Fund for Nature (1999, 2014)
Species of national responsibility	List of species characterized by high or highest national responsibility (Germany)	Gruttke et al. (2004)

(continued)

Table 1 (continued)

Environmental indicator	Measurement and indication	References
High Nature Value (HNV) Farmland Indicator	Proportion of HNV farmland divided by the whole area of open or semi-open farmland (German project)	Benzler (2009), Hünig and Benzler (2017)
Happy Planet Index (HPI)	Multiplying indicator values of wellbeing, life expectancy and inequality of outcomes divided by value of ecological footprint; first report in 2012	Helliwell et al. (2017)
European Grassland Butterfly Index	Assessment of population trends of 17 butterfly species that are characteristic for grasslands in the EU and Europe (separate lists)	European Environment Agency (2013)
European Red List of Habitats	Description and assessment of more than 230 habitat types across Europe with assessment of conservation status and trends by modified IUCN categories and criteria	Janssen et al. (2016)

sustainability indicators). The problem of combined indicators is that it is impossible to reason back to the contribution of the original components.

Everybody is able to measure temperature with a thermometer. However, it is more complex to integrate millions of measurements over space and time to get a trend line indicating global warming. Even if we know much about the relationship between human activities, greenhouse gases and air temperature, it seems to be difficult to estimate the effects of climate change on ecosystems, since for this there is no simple indicator available (IPCC 2014).

Some indicators such as the Happy Planet Index (HPI) integrate the physical environment only to a small extent. Others, for example the Red Lists, are directly connected to ecosystems, populations, species or the biodiversity.

It can be assumed that humans have always observed not only natural attributes such as growth, well-being, and death of organisms, but also the richness of biodiversity. Probably, a species-rich habitat is indicating continuity or sustainability better than a species-poor swamp, saltmarsh or semi-desert ecosystem?

Alexander von Humboldt and Charles Darwin described landscapes as species-rich or species-poor even if they did not quantify the richness (von Humboldt and Bonplandt 1807; Darwin 1839, 1859).

The relationship between the richness of species and area (SAR) has been an object of numerical analysis at least since Arrhenius (1921). Meanwhile, a lot of indicators (or indices) calculating the genetic diversity, size of populations, species diversity, diversity of species assemblages or ecosystems per unit (area) have been established (cf. Hobohm 2000; Hobohm et al. 2019).

Many monitoring programmes for nature conservation record the numbers of individuals, populations or species, and presence-absence data of certain species per unit area as the most common measurements of the biodiversity at landscape to continental scales.

There are currently a huge number of Red Lists or similar indicator systems. However, these often focus on the rarity or endangerment of species groups or habitats in a certain political region. This often has the effect that a species or habitat is evaluated as critically endangered or even *extinct* while the species or habitat type is not threatened in other regions. These terms are often a bit misleading if used in a regional context.

An optimal indicator for alarming trends with respect to the biodiversity should be simple, accurate, informative, and cost-efficient. Such an indicator has not yet been developed, and is most likely impossible.

However, several indicators that already exist might be adapted to achieve greater cost-efficiency or simplicity, for example. In some cases every country has its own methodology and an international agreement or exchange of information would increase the accuracy and information value of the indicators.

For example, *Linum leonii* is a vascular plant species that is restricted to France and Germany with a restricted yet scattered distribution. Thus, France and Germany are responsible for the survival of this species according the Convention on Biological Diversity (CBD). The number of populations of this plant species has declined during recent decades (http://www.floraweb.de/webkarten/karte.html?taxnr=3458, http://www.tela-botanica.org/bdtfx-nn-39429-repartition#; accessed 2/2019). However, *Linum leonii* is a typical example of shared responsibility, which results in a diffusion of accountability in both countries.

Different states or countries in different parts of the world have published lists of species—often endemics or subendemics—for which they consider themselves to have high national responsibility considering not only the distributions within the political region but also the global distribution of the related species and threats. The Federal Agency for Nature Conservation in Germany (BfN), for example, characterized 40 native species (25 animals and 15 plants) as *species of national responsibility* (Verantwortungsarten). Recently, the list was elaborated to include many more species in the category high (!) and highest (!!) national responsibility. Clearly, the list is still incomplete and the categorization is somewhat questionable with respect to global distribution patterns, the number and size of remaining populations and current trends (https://biologischevielfalt.bfn.de/bundesprogramm/foerderschwerpunkte/verantwortungsarten.html; accessed 2/2019). *Linum leonii*, for example, is still not on the list even if other listed plant species have larger ranges and are less heavily endangered. It can be assumed that the awareness of species that occur in more than a single country is lower than country-endemics (Hobohm 2014).

Looking at populations of native species or habitats that are globally rare and declining is one simple measure to indicate problems for regional biodiversity. Another possibility would be to focus on species that are regionally extinct and might simply be reintroduced. An example is *Oenanthe fluviatilis*, which is not on the list of species of national responsibility simply because the species is already extinct in Germany, where it was last seen in the SW of the country (Netzwerk

Phytodiversität Deutschlands e.V. und Bundesamt für Naturschutz 2013). Thus, lists of species categorized as being of national responsibility might also contain species that went extinct at regional scales but still occur in other regions. For example, birds such as *Coracias garrulus* and *Lanius minor* that occurred in almost all regions of Germany in the beginning of the twentieth century and are now absent in most regions of the country (cf. Fartmann et al. 2019) are not yet listed as species of national responsibility.

At regional or national scales the number of native species per unit area (e.g. per hectare, km^2 or 10,000 km^2) would be a rather simple measurement and indication of the richness of a field or landscape. Clearly, the group of organisms or the list of selected species (vascular plants, breeding birds, butterflies, or others) should be predefined. Furthermore, the identification and calculation methodology (space, time, identification key) has to be validated. For such an indicator it is not necessary to define a threshold between low and high diversity, as the count itself could be used as indicator of the biodiversity (cf. Underwood 2014).

3 Concepts, Strategies and Measures

There are various concepts and measures to protect nature, with different evaluation methods are used to describe their effectiveness and success. In the following, a selection of important strategies and applications is reviewed.

3.1 No Species Loss Strategy

A huge number of publications on environmental ethics warn about the loss of species, the loss of ecosystem services, and the loss of cultural and economic values that are linked to a declining number of species on Earth. However, regardless of any justification for the protection of all species, one consequence of every global species extinction is that this loss is irreversible, and irreversibility is contrary to sustainability (Mautner 2009; O'Brian 2010).

No species loss is a target used by different NGOs and governments of many countries. The related programmes often focus on the protection of species that are endemic and/or threatened in a region or country, and on ecosystems that harbour these species.

Indeed, no species loss is not a single strategy but a comprehensive goal including considerations about restrictions and investments, threatened species, their habitats and partnerships, but also by measures directly eliminating e.g. exotic and invasive species, and by captive breeding of rare and threatened species combined with a release of individuals back to the wild. It can be described as the most important goal of biodiversity conservation (e.g., Convention on Biological Diversity).

3.2 Labels

Species characterizations such as *critically endangered*, *key* or *keystone*, *passenger, rivet*, *umbrella*, *protected*, *exotic, alien, invasive, neophyte*, *neozoon*, *subendemic*, *endemic* and *hyperendemic* are labels which primarily do not focus on biological traits or ecosystem functions (Frankel et al. 1995; Hobohm 2000; Moro-Richter et al. 2020). These characterizations are used to highlight, for example, endangerment, restrictedness or other aspects of biogeography, relationship to humankind, or nature conservation management and politics. These normally have a positive or negative connotation, and are used to increase or decrease the meaning of certain species in a regional context.

People, governments and nature conservation NGOs are increasingly aware of which species e.g. are endemic to their homeland, region or country. These labels are also used as a symbol for local identity. Many lists on the internet show how the meaning of endemics is pronounced by national authorities, for example, with the effect that nature conservation policies and measures have to respect their occurrence and distribution patterns.

Biodiversity Hotspots is a further label, not for species but for large regions where the biodiversity is getting *heated*. Although the concept focuses on terrestrial regions and vascular plants, the principle can be adopted to marine regions as well (Ramirez et al. 2017).

3.3 Biodiversity Hotspot Strategy

The concept of Biodiversity Hotspots was introduced by Norman Myers (1988). Accordingly, Biodiversity Hotspots are large regions that meet two criteria. They harbour at least 1500 vascular plant species as endemics, and more than 70% of the primary native vegetation is already destroyed. Currently, 36 regions in the world are recognized as Biodiversity Hotspots (Noss et al. 2015; Critical Ecosystem Partnership Fund 2019). However, especially the shape and borders of the Biodiversity Hotspots is somewhat artificial.

Comparable to the *No Species Loss Strategy*, which focuses on critically endangered species, the concept of Biodiversity Hotspots focuses on large species- and endemic-rich regions with destroyed and threatened vegetation. Both concepts comprise multiple strategies, but primarily they increase the meaning and value of natural entities. *Biodiversity Hotspots* label the large regions and emphasise the necessity to protect the nature of these large regions. Possibly, this characterization—hot (!)—is strong enough to influence nature conservation politics with the effect that further damage might be avoided at least in some parts of these regions.

3.4 Ecological Triage

In a catastrophe with many wounded persons, in a war for example, medical help is prioritized to effective and fast measures related to the people with the greatest need and a realistic chance to survive in a short-term perspective. Triage is a kind of preselection sorting of people when medical resources are limited and the damage is huge. If doctors are numerous and medical help relative to the number of sick or injured people is not limited triage would not be necessary.

Ecological triage aims to use and divide the limited financial resources of nature conservation activities (cost-) efficiently for the survival of the species. Conservationists have to consider a plethora of factors and processes when assessing ecosystems. Often the understanding of food webs, environmental conditions, and all the processes involved is highly incomplete. Political, economic and social factors have to be considered as well (Hobbs and Kristjanson 2003; Burgman et al. 2005; Habib et al. 2016).

Like the preselection of wounded people in a catastrophe, the decision for one conservation measure instead of another may often be wrong and ineffective. However, triage at a lower level of actions might be translated into trial and error approach to selecting measures, which can often lead to successful developments, at least at local to regional scales. If the effect is uncertain, the simplest and most cost-efficient measure should have highest priority.

With respect to the amount of money invested, ecological triage is a common concept practiced at local and regional scales. On the other hand, with the exception of the large nature conservation NGOs such as WWF or Conservation International, there is as yet no institution or administration taking responsibility for ecological triage at the global scale.

3.5 Payment for Ecosystem Services (PES) and Biodiversity Offset Programmes (BOPs)

The money paid for an apple is an investment also in the environmental conditions of apple trees, since farmers only survive if they reinvest a certain amount of that money in maintaining or increasing productivity. Every payment for resources influences the interest in the exploitation and use of resources. It is thus difficult to determine exactly when the first programme was established to invest in ecosystem services. For example, communities began to invest in clean drinking water and effective wastewater systems already many centuries ago.

However, both the number of publications related to Payments for Ecosystem Services (PES) and Biodiversity Offset Programmes (BOPs) and the amount of money invested have shown a dramatic increase and a growing interest in the investment in public goods and services since the 1970s. Until 2014, at least 56 countries had implemented laws or policies that defined offsets for specific impacts on the environment or threats to the biodiversity at landscape scales (OECD 2014; Salzman et al. 2018).

> PES schemes involve payments to the managers of land or other natural resources in exchange for the provision of specified ecosystem services (or actions anticipated to deliver these services) over-and-above what would otherwise be provided in the absence of payment. (Smith et al. 2013, 9).

Water quality and quantity, biodiversity and habitats, well-being and recreation, and the potential of soils for carbon sequestration, for example, are public goods and services related to the physical nature of ecosystems, which normally are not an object of the free-market economy. The aim of biodiversity offsets is to achieve *no species loss* or even an improvement of the conditions of the native biodiversity with a net gain of natural habitats and increasing populations especially of critically endangered species.

The interest in payments for ecosystem services and the number of biodiversity offset programmes has risen around the globe and is still rising, in both developed and developing countries. This might have to do with the flexibility and diversity of political and administrative schemes, with the success of related schemes, and with the growing amount of money invested (Salzman et al. 2018).

Payments for impacts on landscapes and ecosystems such as resource use are often private investments. Trophy hunting for example, is a huge global market. Landowners or governments earn a lot of money from hunters. This money is partially reinvested in favourable conditions of huntable wildlife. *Should we kill animals to save them?* Michael Paterniti asks in his National Geographic article of October 2017.

Many Biodiversity Offset Programmes are still compensation schemes for the use of landscapes, for development projects and damage of the environment. Therefore, the use of landscapes and development of industries and buildings support projects on biodiversity net gain in compensation areas, and in turn the implementation of biodiversity net gain programmes promotes or enables the use, development and damage of ecosystems and landscapes.

However, species diversity net gain is also possible without any increase in the use or development of building measures as an uncountable number of projects of nature conservation NGOs shows. Furthermore, artificial buildings in the landscape such as dams in a river valley can be dismantled by public money with causing an increase in biodiversity. Reduced flooding might be a positive side effect. Thus, Biodiversity Offset Programmes can also be used for decreasing human impacts (Smith et al. 2013).

To strengthen the interest of communities and landowners in providing public services, they should be paid. At the moment, the interest and amount of investments of private persons, organisations and governments to support such projects is rapidly growing. This might be a chance to invert the overall negative trends in biodiversity at local scales at some point.

However, currently it is not possible to get reliable country-related numbers on PES and BOPs. Furthermore, the indication of effects on the environment and biodiversity is rather ambiguous at the moment (OECD 2014; Underwood 2014; Salzman et al. 2018).

Many websites about offset and net gain strategies describe how human development, the growth of settlements and industries, and the damage of natural habitats can be linked with benefits for the biodiversity at another place or in another landscape.

The problem of increasing pressure here and a biodiversity offset there is that many of the threatened habitats cannot simply be recreated elsewhere. Furthermore, even if the whole landscape afterwards shows more species in total than before—net gain—this effect does not necessarily have to be a benefit for the native biodiversity, since for example every cemetery harbours more native species than a pristine bog. The elimination of a bog with a history and peat accumulation of 10,000 years cannot be compensated by any biodiversity offset programme or with a lot of money. Thus, the comparison of counts and numbers alone is not enough.

Top priority should not be a net gain of species or the offset of the damage in a landscape or country but the downgrading of as many as possible threatened species and habitat types in the Red Lists.

3.6 National Parks and Other Types of Protected Areas

The history of nature-protection areas includes taboo zones in a religious context, landscapes and regions for hunting, landscapes of outstanding natural beauty, and regions with rare, endemic and/or threatened species. However, protection of areas for biodiversity conservation is a consequence of the growing human population combined with an increasing pressure on the biota during the last 200 years. Meanwhile, more than 160,000 protected areas in the world cover between 10 and 15% of the terrestrial land and 1–2% of the sea surface on Earth.

The establishment of protected areas became an important instrument in nature protection policies. Nevertheless, protected areas including National Parks often do not reach their targets because diverse human influences are still allowed and illegal activities are often profitable (Soutullo 2010; Mora and Sale 2011).

3.7 Zero Human Influence Strategies and Wilderness

The idea behind the *zero human influence strategy* is that the overall effect of humans on nature was and is extremely negative, and that human beings are not a natural part of most ecosystems. Humans destroy ecosystems and threaten tens of thousands of species on Earth through their exploitation of resources. The agreed international aspiration of National Parks and nature conservation supported by organisations like the WWF—*World Wildlife Fund* until 1986, *World Wide Fund For Nature* now—still is pristine wilderness and the hope that nature is managing itself better through its own ecological processes than through support from humans. Meanwhile it has become evident that, for example, many islands or protected areas on islands with introduced animals such as goat, pig, dog, cat or rat would have a long-lasting problem if these are not eradicated prior to reducing the influence of humans (Diamond 1985; Rodríguez et al. 2006; Whittaker and Fernández-Palacios 2007).

In some parts of the National Park Vorpommersche Boddenlandschaft in Germany, everything including hunting and walking is forbidden, resulting in extremely large populations of boar, fox and other native and exotic predators and omnivores. In these regions, it is extremely difficult to find ground-breeding coastal birds in the open habitats—dunes, saltmarshes, beaches—which they normally prefer. As a consequence, habitats of coastal ground-breeding birds are partially protected by electric fences.

Thus, conservationists and organizations should decide about the intended main goal—wilderness, the survival of native species, or the support of threatened target species. To reduce the influence of humans might be a good idea sometimes. However, in every case the effect of decreasing human influence and abandonment should be carefully observed with respect to the primary goal.

3.8 Restoration Measures and Experiments with New Habitats

Restoration ecology emerged as branch of ecology in the second half of the twentieth century, and focuses on ecological, landscape or habitat restoration. *Ecological restoration* measures are applied for different reasons, comprising aesthetic values, recreational activities such as fishing or bird-watching, and also species conservation targets (Wilson 2010).

A lot of money is spent worldwide on cleaning the water or reducing the impact of waste. Public authorities apply methods of increasing mechanic influence to restore habitats or even landscapes. An uncountable number of restoration measures such as plantations, pollarding willows, removing artificial buildings and structures, restoration of habitats by grazing, cutting, transferring hay of species-rich grassland to species-poorer grassland, eradication of exotic species, repatriation of locally extinct species, and many others are applied. Artificial buildings such as bird or bat boxes are used in the landscape to support certain animals (Harker et al. 1999).

Grazing and cutting are used to reduce biomass and/or productivity, to slow down succession or simply to open the vegetation of a certain type of landscape unit or habitat type. Mowing and grazing are often used in heaths and grasslands, cutting of young trees or shrubs is used in many bogs, fens and swamps, for example across Europe. Mowing is very effective in reducing biomass whereas grazing creates higher environmental heterogeneity at small scales. Both measures stabilize the biodiversity of diverse open and half-open habitat types. In other regions with a continuously decreasing area of natural forest tree plantations are implemented as restoration tool.

However, the results of many restoration measures are questionable with respect to the goal of species conservation, e.g. insect hotels or bird boxes in gardens and parks.

Conservationists normally reject the development of underground exploitation of resources and mining projects, holes in the landscape for extracting sand, clay or rock, or artificial buildings like walls, bridges and so on that have not been there before. Once established in the landscape, conservationists later often call for nature protection because meanwhile rare amphibians, birds, insects, lichens or reptiles have occupied exactly these places. The heterogeneity of urban districts is one of the reasons why the biodiversity of cities is often richer than in the rural surrounding (Barthel et al. 2005).

Biodiversity in general is promoted and stabilized by environmental heterogeneity in space and ecological continuity in time. Thus, a new anthropogenic habitat in the landscape may represent both higher heterogeneity in space and lower continuity over time. In this case, it might be difficult to calculate the overall effect for the nature (Legendre and Fortin 1989; Yang et al. 2015; Hobohm and Müller-Bendict 2018).

However, under which circumstances and in which regions would it be possible to establish new habitats with a presumable benefit for the biodiversity and populations of endangered species?

Industrial agriculture with maximum yield or asphalted urban districts often do not contain any natural structures. Why should these areas not been used for experiments with the goal to offer a habitat for rare and threatened species where they never have been before or where they regionally went extinct?

Why shouldn't a single hectare of coastal arable land be covered for two or three years with shingle and shell fragments for ground breeding birds? Clearly, this hectare should be monitored. In the worst case, no bird will occupy this artificial habitat. Afterwards this place might be ploughed and used for producing crops again.

Why not dig a hole in the ground somewhere in a monoculture of planted trees? Why not cover flat roofs in the cities with hay from species-rich grassland? Why can't spaces under the roof or in cellars be used as space for insects, birds or bats?

Why not think about the establishment of artificial buildings placed on the sea floor to stop further illegal fishing with trawl nets?

There are many ideas like this. Some have already been successfully tested (cf. e.g. Forbes and Kendle 2013). However, such measures should only be established if any damage for the already existing landscapes and habitats can be precluded.

3.9 Eradication of Invasive Species

The introduction in the 1950s to Guam of the exotic brown treesnake, *Boiga irregularis*, which is native in Australia and New Guinea, exemplifies how a fast growing population of an introduced species on an island can threaten the native species diversity. The snake devoured 10 of 13 bird species on this island (Rodda et al. 1992; Burnett et al. 2006).

Since trade continuously increased during the last five hundred years an uncountable number of alien species have been transported and dispersed into landscapes and waters all over the world. As it is impossible and in some cases not necessary to remove every exotic or alien species and as also native species under changing environmental conditions may behave as invaders, some basic facts and rules should be considered with respect to the amount of investment and targets.

First of all, almost all species that went extinct on islands were extirpated by the establishment of one or more new guilds; this means that the introduced species represents a guild which did not exist in the landscape before (Whittaker and Fernández-Palacios 2007). Guam was a snake-free island before the brown treesnake was introduced. The snake simply caught all the birds that did not try to escape because they had never seen a snake or any other aggressive predator before. On many oceanic islands far from the continent, terrestrial snakes, other groups of predators, amphibians, pathogens, humans and the related guilds are not native. The amphibian decline mainly is the result of the anthropogenic introduction of an alien fungus (*Batrachochytrium dendrobatidis*) which damages the skin of amphibians. In many tropical regions, such a pathogen did not exist before it was introduced by accident together with the African clawed frog (*Xenopus laevis*).

Most bird species on islands that went extinct were extirpated not by competition but by new predators (rat, cat), ecosystem engineers (goat, boar), killing men as in the case of the dodo on Rodrigues and Mauritius, or a combination of these (Whittaker and Fernández-Palacios 2007).

Thus, competition between alien and native species is not the largest threat to native species. However, a few examples may be seen as an exception (cf. IUCN Red List).

Furthermore, the situation on small oceanic islands in most cases is more problematic than on large continental islands or mainland regions. The populations of *Prunus serotina*, native to North America, increased dramatically across Central Europe since the tree species was introduced in the nineteenth century (Starfinger 1997). Certain countries in Central and Western Europe currently pay a lot of money to remove *Prunus serotina* from forests and heathlands, for example, as this plant species is well known as aggressive invasive alien. However, the usefulness of these measures of removal depends on the target and the definition of success. The measures are sometimes successful when looking at the removal itself. When looking at structures and species compositions at landscape scales it will be difficult to find any effect except that the whole number of species increased by one: the exotic species. We do not know any example across continental Europe that alien species impacted the structure or species composition of native ecosystems with the effect that a European native species became globally extinct. The situation across the Americas, Africa and Asia may be comparable. The situation of Australia may be different because of the island-like geography, evolution and history.

These are only a few basic facts and tendencies accompanied by several exceptions from the rule. However, the investment against alien and invasive species should be regularly challenged and adjusted (Galil 2009; Veitch et al. 2011; Gutierrez and Ponti 2013).

3.10 Activities Against Illegal Hunting and Trade

Illegal hunting and trade is prominent in almost all regions across the globe. Bushmeat in Africa, traditional medicine in Asia, jewellery, trinkets, accessories, skins, shells, horns, timber from tropical and temperate forests, exotic plants and animals are used for nutrition, health, as aphrodisiacs, for clothing, production of furniture, hobbies and reputation, respectively. There are lots of advertisements on the internet emphasising the rarity of plants and animals that can be ordered.

Less than 8% of all reptile species are regulated by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), although 45% of the species are threatened by biological resource use. At least 194 species that are not listed in the annexes of CITES are targeted by collectors (Auliya et al. 2016).

Trafficking of wildlife and products of animals and plants generates an amount of money between 7 (10) and 19 (20) billion dollars per year (different sources on the internet, e.g. https://www.havocscope.com/tag/wildlife-trafficking; accessed 3/2019). Unfortunately, this is a growing market, already taking position three or four of illegal commerce after drugs, weapons and (maybe) human trafficking including prostitution (Sollund 2019).

From an economic point of view the demand of many products is still dramatically increasing because of a growing world population of humans, an increasing average standard of affluence, increasing possibilities to order illegal products via the internet combined with a heavily overstretched border control of national authorities.

Based on the findings of Kanari and Xu (2012, cf. executive summary) recommendations amongst others are: further research and monitoring of trade dynamics and adjustment of CITES listings, further restriction of the trade of threatened endemic species, effective implementation and enforcement against illegal activities, cooperation with destination authorities to inspect pet shops, physical and online trade, and identification of false documentation.

However, international laws and restrictions obviously do not currently have the power to limit or prevent this crime (cf. Sollund 2019). Thus, what could additionally be done?

One possibility to combat the illegal trade might be legal trade, and to breed related animals in captivity and plants in horticulture with the effect of an increasing supply to sell them more cheaply than the organisms or products from the wild. Legal captive breeding employers already produce thousands of birds, reptiles such as chameleons, snakes, iguanas and mammals for the pet trade every year.

However, there is a twilight zone between legal and illegal trade. Captive-bred animals are often complemented and crossbred with wild-caught animals. Animal farms as way of sustainable production of pets can only be a solution if regulations of animal welfare and nature conservation are strictly controlled and respected. There are, however, also ethical objections. Would it really be an option to produce horns of rhinos, exudates of tigers and bears, and fins of sharks via industrial farming and mariculture even if this would be legal and economically promising?

Another possibility would be to define a positive (green) list of plant and animal species and products that are allowed for commercial trade. This solution would simplify and reduce the work of administrations and border control.

3.11 Captive Breeding and Release into the Wilderness

A frog calling for love in a dating pool?

Conservationists from Global Wildlife Conservation (GWC) together with scientists of the Bolivian Amphibian Initiative started a rather spectacular crowdfunding campaign in 2018 on a dating website.

One single male of a rare Sehuencas water frog species (called *Romeo, Telmatobius yuracare*) lived 10 years after capture in a museum in Cochabamba, and it was unclear if the species went extinct in the wild or not. For many years, scientists tried to find a female or other individual of the Sehuencas water frog without any success. Thus, it was impossible to start a breeding programme with the lonesome male of the museum.

Therefore, the scientists set up a dating profile for *Romeo* (*Match4Romeo*) to find a female *Julieta* in the wild and generated a lot of money from people in 32 countries. With this money, it was possible to organize a joint field trip to systematically looking for frogs deep inside the cloud forest of the Bolivian wilderness, boosting hope to spare this amphibian species from extinction.

Finally, the trip was successful and the scientists returned with five individuals of this rare species. Afterwards they started a breeding programme and there is hope now that the species can survive in both captivity and the wild (information e.g. on the webpage of the Museo de Historia Natural Alcide D' Orbigny, http://cochabambabolivia.net/museo-de-historia-natural-alcides-dorbigny; accessed 2/2019).

The story describes an example of an unusual measure that was established to protect one of tens of thousands of threatened species on Earth. For a handful living frog individuals and a breeding programme the overall investment was much more than 25,000 USD and the effort of many scientists, organizations and donors involved. However, independent of the question about cost-efficiency, the programme brought the best result with respect to the possibilities and the aim, and thus was absolutely successful.

Karlsdottir (2018) published "*General guidelines for managers and supporters of amphibian captive breeding programmes*". This shows how the knowledge in this area has grown since the time of the first captive breeding programmes.

The story about the survival of the Pink Pigeon (*Nesoenas mayeri*) of Mauritius is another success story. This rescue story is connected with the name Gerald Durrell, who initiated the first captive breeding programme. This species had declined to c. 10 individuals in the 1970s. Today the population in the wild is fluctuating around 400 individuals (https://www.durrell.org/wildlife/species-index/pink-pigeon; accessed 3/2019), and there are other examples of successful captive breeding and subsequent release into the wild of several bird, amphibian, reptile and mammal species. Meanwhile, many zoos in the world are involved in conservation breeding programmes and botanical gardens grow rare and threatened plant species. However, these measures have a strong focus on vertebrates and vascular plants and members of other taxonomic groups are still the exception.

Clearly, the goal of such measures in most cases is species conservation without any interest in economic profit. The application of these programmes costs a lot of money and is often conducted or supported by NGOs and private initiatives.

It is an open question if these programmes could and should be enhanced and expanded by increasing their budget, for example through crowdfunding campaigns, support by political authorities or simply by selling pets that are not available in normal markets. Like for medicine that is only available in pharmacies, these special and certified pets and plants might be sold only by zoos and botanical gardens.

3.12 De-Extinction

Would it be a good idea to recreate the extinct Woolly Mammoth (*Mammuthus primigenius*) from still existing genetic material by scientific means? This animal was still alive during the early Holocene, and overkill by hunting was the main reason for its extinction. However, even the best dead individuals preserved in permafrost don't have enough intact genetic material to guide the production of an embryo that could develop in a female elephant (Shapiro 2015).

Selective breeding, cloning and genome editing are the methods that are used and developed to recreate extinct species. It is already possible to sequence and assemble genomes from tissues of animals even if no well-preserved individual exists (Shapiro 2016).

However, to date has not been possible to resurrect any extinct mammal, bird or reptile from still existing genetic material. Thus, there is hope on the one hand and strong ethical arguments against this approach on the other (Kouba et al. 2013; Sandler 2014; O'Connor 2015; Robert et al. 2017). Imagine that the Eurasian mammoth, the thylacine (*Thylacinus cynocephalus*) from Australia and New Guinea, or the dodo (*Raphus cucullatus*) from Mauritius would be resurrected within the next decades. Each rebirth would be a global sensation. However, each young animal could only be raised by a mother of another species. Their behaviour most likely will not be the behaviour of the extinct animal. It will also take a long time to produce a population from which parts might be released to the wild.

Thus, at the moment de-extinction events have not been completed even if certain steps and genetic methods are in progress.

4 Summary and Conclusion

This chapter reviews a selection of environmental indicators, concepts, strategies and measures to evaluate and protect ecosystems and biodiversity. If indicators combine different aspects of the environment or human behaviour it is impossible to reason back to the contribution and power of the parameters involved. Furthermore, it is difficult to evaluate the meaning and accuracy of complex indicators such as the Ecological Footprint.

The currently used and developed concepts and applications to protect the environment, ecosystems and biodiversity have different implications and should be properly monitored with respect to the goal, effectiveness and money invested. Even if there is little interest of a person, institution or political party in species conservation, different strategies, measures and treatments can be used to greening, whitewashing or denigrating a policy, development or institution.

Different regulations, programmes and measures should be adjusted regularly to maintain their effectiveness. The global range and percentage of protected areas including national parks, restoration measures, activities of zoos and botanical gardens, measures of captive breeding with modern methods of genetic engineering, and the money invested most probably will increase also in the future. Thus, at the moment these can be identified as important and promising.

Other concepts such as de-extinction programmes and the development of related methods cost a lot of money today, so far without success. However, sensational resurrection events of plants and animals that are already globally extinct might be expected within the next decades—if genetic material still exists or can be recombined.

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Change: Risks and Predictability

Carsten Hobohm and Sula E. Vanderplank

Abstract Different ecological methods are available to characterize environmental heterogeneity at landscape scales. However, to understand species compositions, distribution patterns within habitats and landscapes, and recent challenges caused by human impacts, a tool for characterizing and quantifying change of environmental conditions over time is needed as well.

Species compositions in general are related to both evolutionary/historical events and current environmental conditions. Dramatic events and changes often have long-lasting effects on ecosystems and species assemblages.

This study deals with the question of how stochastic effects, changing ecological conditions, the introduction of alien species, and dramatic events in general, can be characterized and quantified. We propose some initial ideas for the establishment of an indicator system for constancy and change through time, with respect to the effect size. The effect size depends not only on the magnitude of the factor but also on adaptability of organisms and susceptibility of the ecosystem. These metrics are important for understanding species composition and might be useful for predictability of survival. The species pools of large regions such as continents represent changes during evolutionary times whereas species assemblages of small regions often reflect short-time influences and events in the landscape history.

This contribution is an attempt to combine different orders of change to establish a tool for estimating environmental variability in time. Such a system can be used for calculating the risk of biodiversity loss.

Keywords Constancy · Continuity · Change · Species compositions · Ecological conditions · Introduction of alien species · Risk of extinction

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1 Introduction

Krefeld is a small city in Germany. A rather small society of amateurs interested in insects is working there (Krefeld Entomological Association). Members of this association trapped insects in 63 nature reserves annually since 1989. The catches of the first 26 years were analysed by Hallmann et al. (2017) who found a 76% decline of the mass of insects over this period of time. The media worldwide have reported about this alarming trend which might be representative for all of Europe and also other countries on Earth.

The result was rather spectacular as the insects were collected in nature conservation areas outside urban regions but partially surrounded by industrial agriculture. What is the reason for this dramatic insect decline? Has it to do with the use of chemical components that are dispersed by agriculture, wind and water? According to speculation, industrial agriculture and the use of pesticides close to the traps have caused this effect. On the other hand, lobbyists of the agricultural economy have clearly denied this interpretation.

However, diverse natural and artificial substances can be identified that dwell for a short time or—hundreds and even thousands of years—in the atmosphere and waters. Chemical components in the atmosphere have diverse effects on climate, ecosystem function, biota and health. Anthropogenic emissions comprise highly effective trace gases, and pollutants such as pesticides, acids, nutrients, greenhouse gases and aerosols (Fowler et al. 2009; Monks et al. 2009).

Microbiomes are very small sized compositions of bacteria, fungi, viruses and other small organisms. The understanding of microbiomes inside humans, animals, plants, and soils, and in standing, running and ground waters are of rising interest. However, very little is known about the influence of tropospheric components on microbial communities e.g., in soils and waters, and even less is known about their meaning for ecosystem functioning. Less again is known about the meaning of microbiomes to entire ecosystems and their ecology (Fierer 2017; Serna-Chavez et al. 2013; Fierer et al. 2009; Torsvik and Ovreas 2002).

Species compositions depend on environmental heterogeneity in space (e.g., Dufour et al. 2006; Yang et al. 2015). However, species compositions also reflect their evolutionary and ecological history. Changing conditions may result in adaptation, succession, migration, evolution and extinction. Genetic memory or capacity for learning is essential in vertebrates but also in plants (Gagliano et al. 2014).

Distribution patterns at macro-ecological scales may be used both as a memory tool reflecting the evolutionary history through past climatic change, and for predictability of changing distribution patterns under future climate change scenarios (Tang et al. 2018).

However, a general tool for calculating the effects of changing conditions through time on species compositions, at landscape to regional scales, has not been developed yet.

2 Preliminary Considerations

*Constancy and change of environmental conditions through time influence not only ecosystem functioning, but also the development of human behaviour (*Brim and Kagan 1980*). However, to date we do not have an overarching concept or reference system that allows comparison between the histories of different regions with respect to the magnitude of changing conditions, catastrophes, contingency and continuity. Moreover, these terms are not clearly defined or separated, neither in science nor in the non-scientific communication.*

The considerations outlined here are based on the different preconditions and assumptions that follow:

2.1 Definitions

Before establishing a tool for change in time with respect to species compositions, distribution patterns of rare and threatened biota, and the risk of extinction, it is necessary to clearly define related terms e.g., constancy, continuity, changing conditions, contingency, periodicity, susceptibility, and catastrophe (see below).

2.2 Magnitude of Influence per Unit of Time

The impact of an influence on life, (the ecosystems and biota in a landscape or region), relates to the magnitude of change, i.e. intensity of an influence. The lower the size of the change, the lower the risk of consequences for life, or the need for adjustment. Ecological extreme values in general have a higher impact than average values. The focus on extreme values and events has led to a better understanding of ecological processes and conditions because extreme conditions have a stronger influence on ecosystems and species compositions than mean conditions (de Haan and Ferreira 2006). The mean temperature of Las Vegas, USA, for example, is c. 19.2 °C. This climate value does not say anything about the concrete, normal or extreme temperatures during summer or winter time. However, particularly these matter and influence life. Mersa Matruh in Egypt has almost the same average temperature (19.3 °C). The absolute minimum temperature of Las Vegas was measured as −13.3 °C, in Mersa Matruh it was 1.4 °C. Las Vegas knows frost, Mersah Matruh does not.

2.3 Periodicity, Regularity

*The impact of environmental conditions on biota relates to regularity and irregularity. For example, in landscapes of SW Australia or the Cerrado of Brazil, where fires occur more or less regularly, the risk of ecosystem damage and the extinction risk for certain species is very low since the biodiversity of most habitats in these regions is well adopted to regular wildfires. Fires with devastating effects and damages to the natural world most likely occur where they are severe and unexpected. One example of this comes from the California deserts where the invasion of annual grasses creates a fuel layer that did not previously exist and allows fire to carry across deserts. The lack of fire in the evolutionary history, due to the spacing between individuals and the ephemeral nature of annual wildflowers, means that fire-tolerance has not evolved in the native species found there (*Minnich 2008*).*

2.4 Susceptibility of Ecosystems

The same cause may have different effects depending on the susceptibility of the ecosystem. For example, global warming leads to rising sea levels. However, many coastal regions on earth are uplifting due to geological processes. Therefore, coastal regions of Scandinavia, Scotland, parts of the Mediterranean, or some of the Caribbean Islands, for example, are little affected by relative sea level rise.

*An introduced species might have a small effect if a native species with a similar niche is already present. The effect may be dramatic if the introduced species represents a new guild (predator, for example). This is the reason why the Brown Tree Snake (Boiga irregularis) from Australia and Indonesia had dramatic effects on the biodiversity of Guam and caused the extirpation of a dozen bird species on this island (*Savidge et al. 2007*).*

2.5 Date of Event

The longer the time since a catastrophe occurred, the lesser the memory which means both human memory and aftermath that can still be recognized on the landscape. If all individuals of a natural forest are of the same age then most likely a fire or another catastrophe destroyed the forest during a special event. Mucina and Wardell-Johnson (2011) *distinguished three groups of temporal scales: short-term (e.g., flash-floods, landslides, tsunamis, earthquakes, extensive fires), mid-term (e.g. glacial scouring, marine transgressions and regressions, drought-pluvial cycles, desiccation of lakes), and long-term (e.g., drift of continental plates, isostatic and epirogenic uplift, continental scale erosion).*

Hopper *(2009) and* Mucina and Wardell-Johnson *(2011) introduced and discussed the concept of old and young landscapes. Old landscapes are characterized by relatively stable and long-lasting climate, no glaciation during the Pleistocene, and tectonically inactive surfaces with infertile soils dominating. In contrast, young landscapes are those that originated from volcanic eruptions, rapid tectonic events, or that were transformed by glacial regimes during the Pleistocene. Many young landscapes have high erosion and sedimentation rates, steep slopes, and young and fertile soils.*

Such a concept might be used as a basis for an indicator system or tool incorporating geological and climate stability, and other aspects such as fire frequency, which indicate constancy, change and the risk of an environmental disaster at local scales.

Hobohm and Müller-Benedict (2018) *studied the relationship between endemism and the physical environment of islands. They found that endemism on islands was richest under more or less ecologically stable conditions in combination with high environmental heterogeneity in space. As indicators for continuity in time they used two simple systems, one for landscape and the other for climate continuity over time, each with five levels of intensity.*

However, other factors such as human influences, changes in land use, application of pesticides and fertilizers, the presence of pathogens or invasive species, and unfortunate casual combinations of ecological conditions, can result in a disaster. The magnitude of changing environmental conditions via human influence should also be represented by an operational indicator system.

3 The Meaning of Changing Conditions for Landscapes, Ecosystems and Biodiversity

Figure 1 shows different examples of constancy and change over time. Constancy is a condition without any change. An example for environmental constancy (a)—at least for extended time periods—is the concentration of atmospheric nitrogen (N_2) and certain inert gases. Examples for a sine curve (b) are the regular periodicity of daylight and darkness during the night or annual seasonality of temperatures or precipitation rates. These may be considered regularity or periodicity. However, for distinguishing regularity/periodicity and irregularity, both terms have to be quantified with respect to amplitude or steepness of the slope.

The graphs of (c) and (d) show two different types of—at least in the end—downwards sloping curves. The decreasing amount of a resource caused by exploitation might be an example for both of them. (d) has a larger effect size and irregularity than (c).

A severe disaster may kill all life in a region. A catastrophe or disaster can be defined as an event with very negative consequences for populations and individuals (reduced fitness/reproductivity/death) or for biodiversity and species numbers.

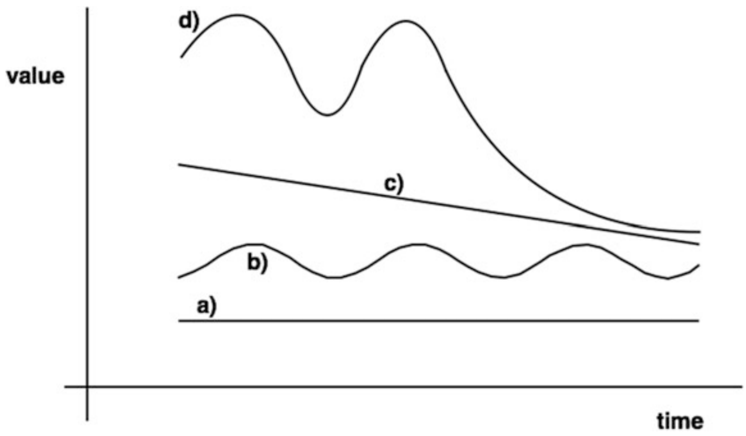

Fig. 1 Constancy and discontinuity in time; (**a**) constancy, (**b**) periodicity (sine curve), (**c**) continuous decline, and (**d**) a discontinuous decline with a larger effect size and irregularity than (**c**)

Stochastic effects and change have been studied on very different levels of individual fitness, population dynamics, ecosystem functioning, biodiversity and evolution (cf. e.g. Wrege and Emlen 1991, Stuessy and Ono 1998*,* Doak et al. 2005*,* Nabe-Nielsen et al. 2010, Melbinger and Vergassola 2015*).*

Catastrophes and disasters may comprise events such as volcanic eruptions, landslides, earthquakes, extreme temperatures, severe storms, floods, droughts, extreme heatwaves and extensive fires, tsunamis, the spread of diseases and pests. However, for a single insect, a lack of pollen and nectar may also be a serious problem. Thus, the term catastrophe is relative.

Creeping processes can have strong effects on ecosystems and biodiversity. Cumulative impacts must also be considered in areas that are repeatedly disturbed; e.g., it is not just the magnitude of a disturbance but the time since the previous disturbance, which dictates the extent of negative impacts to a system. Invasive species such as rats, goats, pigs and cats have already resulted in the extinction of many native species on islands. In accordance with the Convention on Biological Diversity (CBD) every irreversible extinction can be called a loss and disaster.

Different aspects of change in the context of environmental continuity and change at landscape scales could be operational: (1) human influence, (2) geology/landscape/surface/soils, (3) climate/weather extremes, and (4) others.

Combined with regularity vs. irregularity, and short-term, mid-term, and long-term changes, these influences may have totally different effect sizes.

Natural processes such as volcanism and cultural impacts such as the use of pesticides can destroy whole landscapes and ecosystems. Nowadays, a great risk for the survival of different ecosystems and species is human activities. The global application of fertilizers, pesticides, medicines for domestic animals, and the dispersal of pathogens, is today affecting much larger areas than any other natural process or event.

Earthquakes, tsunamis and floods can kill many people and damage buildings. In contrast, the effect size for natural and semi-natural landscapes is often small or negligible. Similarly the impact of climate change may be much worse for people living at the coast than for coastal ecosystems that are adopted to wind and water dynamics such as tsunamis, currents, tides and storms since for millenia or even longer periods of time.

According to IUCN Red List (2019; accessed 4/2020) agriculture, forestry and aquaculture comprise by far the most threatening activities for habitats and species on Earth. 31,030 species are threatened worldwide (categories CR, EN, VU), 6523 are critically endangered (CR).

Biological resource use including logging and wood harvesting, hunting, collecting wild plant material, fishing and harvesting aquatic resources is the second largest threat. Biological resource use is the most important threat to the oceans, and the second most important threat for organisms on terrestrial lands.

Alien species are species that live outside their former natural distribution, i.e., in regions where they have been introduced. Invasive species are those alien or native species that displace other species and become dominant. In many cases a rapidly growing population in a region where a species is not native has the effect of changing species compositions and structures (ecosystem engineering). However, the influences and effects on ecosystems are diverse. For example, goats or rats on islands where the relating ecological niche was not filled before the introduced species occurred may cause the loss of native species such as ground-breeding birds or vascular plants. An example is the arrival of annual grasses to the worlds deserts and semi-deserts, which create a persistent fuel source, in contrast to the ephemeral native annuals that blow away once they have dessicated, and therefore carry fires in ecosystems that are not adapted to fire.

The introduction of thousands of alien species in continental Europe in contrary is not documented to have caused the loss of any native species yet. The reason for a lower risk might be the combination of a much larger region and the former occupation of niches (cf. Tilman 2004; Ehrenfeld 2010).

Climate change and severe weather events take an intermediate position compared to other threats, in most cases. Changing precipitation rate will in many cases have a stronger influence on ecosystems and ecosystem services than changing temperatures. Decreasing temperatures and precipitation rates might have a stronger influence on ecosystems than increasing values. The reason for this assumption is the distribution pattern of biodiversity across the Earth with a high species diversity towards high precipitation rates and temperatures in the tropics and only few biota living in dry and cold regions. Notably it is also true that biotic interactions increase towards the tropics (e.g., herbivory, predation, etc.) and a lack of climatic change in deep time is a presumed driver for these phenomena (Hargreaves et al. 2019).

Geological events including volcanism, earthquakes, tsunamis, avalanches and landslides take the last position as a threat for all habitat types. Thus, the threat exists, but does not play an important role compared to many human activities.

Table 1 Number of critically endangered (CR) and threatened (EW, CR, EN, VU) species in the world according to the IUCN-Redlist (IUCN 2019), and number of threatened habitat types across Europe (EU 28+) according to Janssen et al. (2016) and Gubbay et al. (2016)

Habitats worldwide	No. of critically endangered species acc. to IUCN Red List (CR)	No. of threatened species acc. to IUCN Red List (EW, CR, EN, VU)	Habitats in Europe	No. of threatened habitat types in Europe (28+)
Marine oceanic and deep benthic	44	288	Marine habitats (Baltic Sea, North-East Atlantic, Mediterranean Sea, Black Sea)	45 (out of 257)
Marine neritic and intertidal	156	1017		
Marine coastal/supratidal	111	567	Coastal	13 (out of 30)
Forest	3258	15,250	Forests	10 (out of 42)
Shrubland and savanna	813	4400	Heathland and scrub	6 (out of 38)
Grassland	386	2352	Grasslands	26 (out of 53)
Wetlands	1605	6585	Freshwater	10 (out of 26)
			Mires and bogs	7 (out of 13)
Rocks, caves, desert	136	585	Sparsely vegetated	3 (out of 31)
Artificial/terrestrial	219	1492	–	–

The terrestrial habitats with most threatened (19,867) and critically endangered (4432) species in the world are forests and wetlands. More inhabitants of the shallow seas are threatened than inhabitants of the open and deep sea (Table 1).

The pressures on oceans worldwide (IUCN Red List) and the pressures on the marine environments of Europe are comparable according to the first comprising Red List of Habitats (Janssen et al. 2016; Gubbay et al. 2016).

The most severe threats to the ecological conditions and biota of the North East Atlantic to the Mediterranean Sea, to the Black Sea and Baltic Sea are related to pollution, biological resource use, natural system modification, urbanisation, residential and commercial development.

Compared to the global assessment, the situation for terrestrial habitats in Europe is slightly different (Table 1). European terrestrial ecosystems are mainly threatened by agricultural intensification, abandonment of domestic animals in open landscapes on the mainland, urbanisation, roadworks, transportation, and modification of natural systems.

Grasslands, mires and bogs are the most threatened habitat types in Europe. The situation for forests here is much better than in other parts of the world because the whole area with forest in total has been increasing for many decades.

The threats (Table 2) can be used to create a tool for characterising change through time at landscape scales with respect to effect size and susceptibility.

Which processes can damage whole landscapes, which can have strong effects, and which are more or less unimportant? Which ecosystems are affected by natural processes and which are affected by human activities?

4 Effect Size of Environmental Change in Time at Landscape Scales

Table 2 combines many of the former considerations (i.e. numbers of threatened species according to the IUCN Red List (IUCN 2019), results of the Red List of European Habitats according to Janssen et al. (2016) and Gubbay et al. (2016), and the consideration of Mucina and Wardell-Johnson (2011). The table can be used as a simple scheme to characterise changing conditions over time at landscape scales with respect to the risk for ecosystems and biodiversity.

By giving numbers for each aspect (grid cell), it could also be used to quantify environmental change in time or to define catastrophes for landscapes. However, the numbers should be weighted. If, for example, life on an oceanic island is totally destroyed by a severe volcanic eruption, then the other aspects at that very moment are of no relevance any more.

This table might also be used as a traffic light with green for low and red for high-impact effects.

5 Conclusion

Environmental conditions can be constant, they can change regularly or the changes can be strong, sudden, unexpected and represent catastrophes.

The effect size depends not only on the environmental parameters but also on the adaptability of organisms and the susceptibility of the ecosystem.

To date, a simple quantifying system that would indicate the effect size probability of changing conditions over time has not been developed. Thus, the contribution presented here can only give preliminarily ideas to the discussion.

It would be challenging to have such a tool be comparable to indicator values for heterogeneity in landscapes (which already exist) to estimate the possible effects such as loss of biodiversity, or pressure on ecosystems, which are related to

Table 2 Effects or risks of environmental change in time, susceptibility of habitats at landscape scales

Factors (threats)	Effect/risk for biodiversity		
	No/low	Intermediate	Strong/high
Agriculture, aquaculture (crops, plantations, livestock farming)	Low intensity	Intermediate intensity	Intensive production of crops and livestock
Biological resource use, hunting, gathering plants, logging and wood harvesting, fishing and harvesting other organisms from water bodies	Sustainable or not existent		Illegal and/or legal and intensive
Introduction of diseases/ pathogens, viruses, fungi, bacteria and/or hosts (insects)	Dry conditions, low risk		Wet/humid conditions, high risk
Introduction of plant or animal species, non-native or native invasive species	Mainland regions	Large continental islands, Australia	Small oceanic or continental islands or habitat isolates
Natural system modifications, fire and fire suppression, abstraction of water	No fire or regular moderate fires at local scales, no water abstraction	Change of fire frequency	Irregular frequency of hot fires or high intensity of artificial fires, and/or intensive abstraction of water
Residential and commercial development, traffic, housing, construction of roads, tourism	No or slow development	Moderate development	High intensity or intensive development
Extraordinary periods of severe weather: precipitation rate or temperature		Radical increase relative to average	Radical decrease relative to average
Severe storms/tsunamis	No impact	Regular impact	Strong and irregular impact
Pleistocene	No glaciation or low indirect influence (wet tropics)	Strong indirect influence (cold desert conditions, etc.)	Covered with glaciers
Energy production and mining, oil, gas, renewable energy production		Punctual, moderate probability of new exploration	Intensive/large scale
Pollution, production and release of domestic, urban and/or industrial waste, pesticides, medicine, hormones, excrements, nutrients, other chemical components	No or punctual use and release of low amounts	Temporarily, use increasing	Intensive/ large-scale

(continued)

Table 2 (continued)

Factors (threats)	Effect/risk for biodiversity		
	No/low	Intermediate	Strong/high
Volcanism/landslides	No volcanic activity, no landslides	Low or intermediate risk of volcanic eruption or landslides	High risk of destructive eruption or landslides

modelling environmental change in the future. Furthermore, such an indicator system might help explain differences in species composition and diversity at all spatial scales. Spatial heterogeneity and the variability of ecological conditions over time are important factors for understanding assemblages.

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Economy on Top, Nature on the Brink? A Closer Look on the Relationship Between Economic Power and Threatened Nature

Thomas Gaens, Volker Müller-Benedict, and Carsten Hobohm

> *Sorry, did I say nature? We don't call it that any more. It is now called natural capital. Ecological processes are called ecosystem services because, of course, they exist only to serve us. Hills, forests, rivers: these are terribly out-dated terms. They are now called green infrastructure. Biodiversity and habitats? Not at all à la mode my dear. We now call them asset classes in an ecosystems market. I am not making any of this up. These are the names we now give to the natural world.*
> *George Monbiot 24 July 2014*
>
> *Put a price on nature? We must stop this neoliberal road to ruin. The failure of the markets hasn't stopped the rise of the gobbledygook-filled Nature Capital Agenda. (https://www.theguardian.com/environment/georgemonbiot; accessed 3/1/2020)*

Abstract With this contribution we want to take part in the analysis of the relationship between economy and environment/ecology. We analysed the relationship between indicators of economic power, affluence, inequality, and pressure to the biological diversity of countries.

Furthermore, we ask the question about the responsibility of national governments for the nature inside and outside of countries with respect to their economic potential. The systematic developed here may contribute to the discussion about the relationship between economy and ecology.

Main questions are:

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Are the threats to nature related to or independent of economic factors?

Is the pressure to nature related to economic richness or poorness?

How strong is the relationship between inequality and threats to biodiversity?

Is the number of threatened species related to the natural richness or other geographical factors?

How could a scheme of economic responsibility for nature look like?

We proposed various hypotheses: the hypothesis that pressure to the biodiversity is related to the economic power of a country (*Richness* or *Poorness Hypothesis, Inequality Hypothesis, Environmental Kuznets Curve*), that pressure to nature is linked to the overall natural richness (*Biogeography Hypothesis*), or to other social or geographic factors such as population density, and alternative hypotheses.

We used correlation and multiple linear regression (MLR) analyses, and tried to disentangle the relationships between (1) economic power, (2) geographical factors including natural species richness, and (3) endangerment of the biota as response variable, based on data of 188 countries.

Different regression analyses show a significant relationships between the number of threatened species, natural richness, and economic power (GDP).

We used GDP, GDP per sector, GDP per capita, Gini and Palma as economic indicators. In every case the contribution of GDP was highest. Also inequality showed a significant relationship to the pressure on biodiversity. Many other relationships were weak and/or not significant.

Countries with high natural species diversity normally represent high numbers of endemic species as well. The amount of endemics on the other hand, shows a strong relation to the number of threatened species even if *endemic* and *threatened* does not mean the same. Endemics in our selection are restricted to a country, but must not be threatened. Threatened species often occur in more than one country, and thus, must not be country-endemics. We found that the amount of threatened species mirrors endemism and the overall species richness.

Economic power and inequality, natural species richness and endemism, and population density seem to be key factors for the understanding of pressure to nature and the amount of threatened species. Thus, we confirm both the meaning of economies (*Richness Hypothesis* and *Inequality Hypothesis*), and biogeographical factors (*Biogeography Hypothesis*). Furthermore, we promote the hypothesis that population density is also relevant (*Population Density Hypothesis*).

In a second step, we identified different groups of countries with respect to their potential to invest in the development of environmental initiatives and support for nature conservation programmes and measures.

We used the number of threatened species in combination with economic power (GDP and GDP per capita) as proxy for the potential and responsibility. Economically powerful countries with high numbers of threatened species can be characterized as countries with high responsibility. According to the same systematic, economically weak countries with low biodiversity and low numbers of threatened species can be classified as less responsible.

Economic powerful countries with low numbers of threatened species are identified as countries with a great potential to support biodiversity conservation initiatives at global scales. These countries might effectively support direct investments in species and habitat protection in their own political region and other parts of the world as well.

In contrary, economically less powerful countries with high numbers of threatened species normally do not have the possibility to protect their landscapes and biodiversity effectively.

Keywords GDP · GDP per capita · Inequality (Gini Palma) · Species richness · Endemism · Threatened species

1 Introduction

The relationship between economy and biodiversity includes benefits to humans including immaterial values, destruction of ecosystems, biodiversity loss resulting from resource use, and the impact and likelyhood of natural disasters as rebound effect (Fig. 1).

According to *Political Economy Theories* as well as to the *World System Theory* the economically richest countries in the world are destroying the nature much more than poor countries since they are more developed, use more resources, produce more waste, and damage whole ecosystems. Furthermore, like cuttlefish they spread their tentacles to distant regions and developing countries to satisfy their hunger on energy and other resources. Thus, the number of threatened species is linked to the economic power (*Richness Hypothesis*). Is this true or exactly the other way around (Fig. 1)?

People of economically weak countries and communities do not have any possibility to treat their natural surrounding with care. The people have to use resources, to hunt, to fish and to grow food for short-term survival of the still growing tribes. It is impossible to reduce the use of energy, material and food which is small at all. Furthermore, "*poor countries do not have the luxury of exporting their problems or of using indigenous technology to 'fix' them*" (Frickel and Davidson 2004: 104). In contrary, they might even have to take care of additional waste from richer countries because of economic dependencies. Thus, most threatened species and their endangerment are linked to economically weak countries (*Poorness Hypothesis*).

Furthermore, a positive relationship between economic inequality and the pressure to nature would confirm the *Inequality Hypothesis* (Mikkelson et al. 2007). According to the *Environmental Kuznets Curve* the pressure to the nature is highest in nations that undergo industrialization (Kuznets 1955).

However, as can be derived from Human Ecology, the endangerment of ecosystems, plants and animals could also be independent of the economic power of the countries since the number of threatened and endemic species often simply reflects the overall richness in the nature, i.e. the whole number of plant and animal species of a country. The probability of a country to harbour threatened species is high if the number of species in total is high. The biodiversity of the Tropics is much richer than the biodiversity of the Arctic/Antarctic. The more species are living in a country the higher is the probability to find also species that are threatened with extinction. The

Fig. 1 Madagascar is a country with a still growing human population, with an outstanding and unique biodiversity including high rates of endemism. Many species are threatened with extinction. The photographs show a market place in Ambovombe and the globally unique thorny scrub vegetation with a Baobab tree (*Adansonia za*) in the S of Madagascar (photographed by Carsten Hobohm)

relationship between overall biodiversity and number of threatened species should be strong (*Biogeography Hypothesis*).

Other hypotheses may be proposed as well. For example, it seems possible that the number of people in a country or areas of a country are variables that are related to the pressure on the natural surroundings, i.e. number of threatened species (Asafu-Adjaye 2003; Mikkelson 2013).

In which way economic behaviour affects nature is of central importance when discussing the chance of future conservation strategies. From the influence of individual behaviour (e.g. Kennedy et al. 2015) to the role of international institutional penetration (e.g. Schofer and Hironaka 2005), researchers try to reveal what mechanisms produce which effects on the environment. Such analyses usually come along with some more or less precise advice how to treat the mechanisms unveiled to lower the environmental pressure addressed. It often remains unclear though what the odds are for such suggestions to be turned into reality and to show a globally relevant effect at the end. Economic power is one of the prime enabling and limiting factors for governmental environmental protection to directly finance management of the environment or to finance means of education, research and awareness which are fundamental to realize the environmental impact of human behaviour and, where necessary, to alter it on an individual as well as on a collective level.

The economic framework of our globalized world may—at least sometimes—be accounted for, when discussing the environmental effects of economic behaviour, but is usually neglected when working out possible solutions to alter these effects. The more generalized action is demanded, the less clear it is who has to act to which degree to reach a postulated goal.

Vlek and Steg (2007:14) for example stated: *"To ensure environmental security and sustainability, the overall policy goal certainly must be to reverse the trend of gradual environmental deterioration, locally as well as globally. Some key aspirations are: (1) safeguarding the availability of basic resources, (2) protecting human health from environmentally risky conditions, (3) ensuring sufficient quality of human living environments, (4) protecting natural areas with their wildlife, and (5) promoting greater harmony between humanity and (other) nature." There is no question that these are worthwhile goals. But which actor is addressed in which way? Who has perhaps already taken the first steps in the right direction? Who might easily contribute far more effort? And who is capable of acting in the proposed way at all?*

We therefore took a closer look on the relation between the economic condition of the countries around the globe and the conditions of their biodiversity. Is there a direct link between the both and if yes, what does it look like? Since the economic status of a country and the status of its environmental condition are multilayered phenomena that cannot be measured easily as a whole, we focus on the question whether there is a link between the economic power and the extent of country-related biodiversity and endangerment.

It is already known that "*basic material conditions (...) as population, economic production, urbanization, and geographical factors (...) affect the environment*" (York et al. 2003: 279), that economic growth is a threat to ecosystems (Asafu-Adjaye 2003; Hoffmann 2004; Mikkelson 2013) and it is assumed that biodiversity loss increases with higher inequality, when controlled for basic material conditions (Mikkelson et al. 2007). Thus, something has to change if biodiversity should be protected in a long-term perspective. But who is in duty to act? And who is capable of acting at all? To what degree can global biodiversity loss actually be tackled under the current circumstances of a globalized world?

With this contribution we analyse the relationship between the economic power of a country, the natural species richness, endemism and the endangerment of native biota. Furthermore, we try to find out which combinations of economic power and pressure to nature are realized, and where the potential to act might be highest.

2 Theoretical Background

Prices mirror values, somehow. This is one of the reasons why economists began pricing the nature (cf. Costanza et al. 1997; May 2017). Without a price, the living world could not easily be valued. There was hope to open the eyes for natural values by showing benefits of ecosystem services translated in dollars. However, there are strong concerns on pricing of ecosystems and ecosystem services. The natural capital agenda might be interpreted as nature has no value unless it could be translated into money.

Tables 1 and 2 show total values and annual exchange rates of money. Some are related to the nature, others not. Furthermore, payments may have positive and negative effects on ecosystems. However, both tables indicate that the estimated prices of the whole nature and ecosystem services is rather small compared to other economic values of the global market. This is somewhat astonishing since cultural, social and economic values in the world cannot exist independent of environmental conditions, natural processes, ecosystems and natural resources. Cultural life depends directly and indirectly on ecosystem services.

Agriculture, forestry, fish, mineral, fossil and renewable energy production represent undoubtedly ecosystem services. Thus, at least the amount of GDP in these sectors should be added to get a more realistic view on ecosystem valuation. However, in this case arable land would represent the most important nature capital in dollars (in total and per hectare; cf. CIA 2018, 2019, 2020).

Prices are not at all the only values. Other values such as intrinsic values of a species, beauty of a landscape, sustainability, future of the children exist independent of recent flows of money and markets (Chan et al. 2016; Ott and Hendlin 2016; Jetzkowitz et al. 2017). Very often people value something in the moment when it irrevocably has gone, e.g. the last individual of the Chinese River Dolphin (*Lipotes vexillifer*). People can feel the loss even if they never have seen this animal. In this case, the contemporary material and immaterial values have gone with the last individual.

However, the reason for this extinction might have been pollution as side effect of the economic influence on the natural surrounding of the dolphin.

Theoretically, several relationships between economic power, biodiversity and the extent of endangerment are possible. As York et al. (2003) pointed out,

Table 1 Estimates of economic values (stocks according to Desjardins 2017)

	Total value (trillion USD = 10^{12} USD)
All derivative contracts	544–1200
Global real estate	217
Global dept including that accumulated by governments, corporations, and households	215
Global stock markets	73
The world’s gold	7.7

Table 2 Estimates of annual costs/benefits (flows); p.p. own calculation based on numbers in refs

	Estimated annual costs/ benefits (trillion USD/yr = 10^{12} USD/yr)	References
Gross world product (GWP)	80.27–127.8	CIA (2018, 2019, 2020)
Entire biosphere	33 (16–54)	Costanza et al. (1997)
Agriculture (5.9%–6.4% of GDP)	4.4–8.2	CIA (2018, 2019, 2020)
Production of natural resources incl. oil, gas, coal, minerals, forest products (5.9% of GDP)	4.3–7.3	CIA (2018, 2019, 2020)
Ecosystem services of the oceans 2007	>3.61	Russi et al. (2013)
Transnational crime	1.6–2.2	May (2017)
Food production	1.3	WWF (2020)
Value of agricultural output in the EU 2017	0.48	European Union (2018)
Value of forestry products 2018	0.27	FAO (2020)
Total benefits by coral reefs in 2030	0.072	Lomborg (2014)
Investments to preserve 50% more coral reef by 2030	0.003	Lomborg (2014)
Illegal logging	0.052–0.157	May (2017)
Illegal mining	0.012–0.048	May (2017)
Illegal wildlife trade	0.005–0.023	May (2017)
Coral reef services 2007	<0.0012	Russi et al. (2013)

assumptions about the environmental impact of human behaviour can be derived from three main theoretical perspectives: *Modernization Theory*, *Political Economy* and *Human Ecology*. The related theoretical frameworks can be applied to the distinction between responsibility for the environment and accountability for economic actions.

In the eyes of classic Modernization Theory, the impact of the economic performance of a country on the human environment depends on the stage of its economic evolution. Beneath a certain threshold of economic development or affluence, economic performance may cause damage, e.g. due to a dominance of the agricultural sector, which is expected to have more negative effects on nature than a service-oriented economy or lacking technology for clean production. But, from this perspective, its harmful effects will eventually be overcome by the possibilities of protection and regeneration it creates by "*economic feedback mechanisms*" (Beckerman 1992: 483). Once the economic development reaches the turning point it may run in a sustainable way—either "*automatically when countries* *develop*" (Grossman and Krueger 1995: 371) or "*via an induced policy response*" (ibid: 372). The reasoning for this evolutionary thought relies on the two assumptions that a) the environmental benefits of technological progress outweigh or even exceed its negative impacts and b) societies generally treat their environments as a "*luxury good*" (York et al. 2003), which will be incorporated into the capitalist logic of improvement through competition, once the existential needs of the people are satisfied—or in other words, once the market of existential goods is saturated and investors turn to more sophisticated demands to meet, to keep their business running (for a critical view on the understanding of endangered species preservation as a market good see Shogren et al. 1999 and Erickson 2000).

In summary, it is predicted that economic progress first may cause problems which, however, will get fewer as the development continues, and from some point on even may decline. Over time, this is expected to lead to an inverted U-shaped correlation between economic growth and environmental damage, the so-called environmental Kuznets Curve (for an overview on research related to the Environmental Kuznets Curve approach see Stern 2017, cf. also Aşıcı 2011).

Thus, by its basic neoliberal rationale that progress will finally solve all the problems it created before, modernization theory gives a scientific justification for the subordination of environmental protection to economic performance. Accountability for a harmful treatment of nature is rejected with reference to the loose promise that the same behaviour which led into crisis will afterwards solve the crisis. Although there lies some hope in this thought, the insistence on modernization as rationale raises the suspicion that modernization theory rather rests on the neoliberal narrative than on solid empirical groundwork (see ibid).

A specification of Modernization Theory is the *Ecological Modernization Theory*. Its basic idea is, similar to its economic equivalent, that increasing modernization is the appropriate way to decrease pressure on our environment (e.g. Mol 1995). Its reasoning though goes beyond the economic sphere and takes into account the institutional change which comes along with the modernization of society. The argument here is that modernization as a whole includes an increasing awareness for the importance of a healthy environment for the well-being of mankind, given that enough individual and political freedom exists. Companies as well as political institutions are then expected to treat ecological progress as a genuine goal rather than as a means to more power or more returns, respectively (see York et al. 2003).

Thereby, its ecological enhancement leaves the inherent optimism of original Modernization Theory behind. By recognizing the importance of conservation as a genuine goal, it acknowledges that someone has to deal with the environmental consequences that arise from economic progress, because these will not simply disappear as a side effect of further modernization. According to the institutional alignment of the theory, the accountability for doing so lies a little more within the political than within the economic sphere of society. Nevertheless, the theory also claims that modernization will turn out just fine if enough political freedom for development is given. While there is some evidence that international institutional penetration can reduce environmental damage (see for example Schofer and Hironaka 2005), it remains unclear whether such institutional impact can eventually evolve to a degree it can compete with the decentralized economic powers unleashed by a globalized market—and if yes, whether it can do so in time (for a critique on case study evidence for Ecological Modernization Theory see for example York 2004; for empirical findings that contradict assumptions of Modernization Theory see York et al. 2003).

In contrast to Modernization Theory, *Political Economy* assesses economic growth spawned by a competitive economy generally as harmful for the environment, which is regarded as a common good rather than a luxury good. From this perspective, there are no sufficient incentives for private enterprises, dedicated completely to the maximization of profits, to take care of the preservation of nature. To stay competitive, they need to reinvest their returns as efficiently as possible, which usually means to further expand business. An investment in sustainable economic activities would lead to short-term market disadvantages, even if it would pay off in the long term. This is why "*firms tend to minimize, or even undermine, progress on ecological goals*" (Schnaiberg et al. 2000: 1). National institutions are also interested in further economic growth as an increasing GDP also means increasing income for the government, and therefore are unwilling or unable to enforce striking regulations upon the private economy (Schnaiberg and Gould 1994; Schnaiberg et al. 2000). Instead, they are expected to enact environmental laws of "*primarily symbolic quality*" (Newig 2007: 276) to serve civic demands that may arise along with growing affluence which actually "*manage* rather than *resolve* environmental problems" (ibid: 291, emphases in original).

We here have the opposite of classic Modernization Theory. *Political Economy* assumes growth as generally problematic and is critical of the trusting idea that an economy slanted towards expansion will develop sufficient protection features for its nature, may it be alone or under the lead of political institutionalization. From this perspective, the originators of environmental problems should be held accountable for their actions. The hope that this will actually happen under the current political circumstances is low, though.

However, *Political Economy* does not always impute to those in charge that they do not realize or that they ignore the issue that increasing devastation of the environment has negative effects on the well-being of mankind. In fact, some theorists even impute something worse to them: To source out the local risks of economic growth to lower-developed countries. Foster (2002: 60ff) shows some evidence that such a process must not be understood as a sole side-effect of power relations, but may be processed even on purpose.

According to the *World System Theory*, three types of countries exist: (1) Core countries, which control the markets in this globalized world and use their power to exploit the rest of the world (e.g. by importing resources while exporting waste or by sourcing out the production of goods with a highly negative impact on nature when not equipped with costly preservation arrangements), (2) semi-periphery countries, which seek to catch up with those on top and therefore accept their rules, while exploiting those countries with the least power in the global system themselves, which are (3) the periphery countries that have no power and hence are forced to play along with the economic rules that are imposed on them in the context of globalization (Roberts and Grimes 2002; Wallerstein 1974; York et al. 2003; Hoffmann 2004).

By categorizing countries into hierarchically ranked groups of economic and political power, the theory overcomes the simple scheme of assigning the whole accountability for an action to the executing actor alone, Political Economy can be criticized for. By acknowledging international power relations, it decouples the accountability for environmentally harmful behaviour from the pure economic performance and demands a closer look on possible dependencies from which this behaviour may emanate. In this view, the core countries are not only accountable for their homemade environmental problems but also for international contributions causing disasters by exploiting resources far away.

Human Ecology contributes to the analysis of the environmental impact of human behaviour by reminding us that processes are always embedded into an environmental frame and hence, both are related to each other. Across countries there are different environmental settings, e.g. different climate zones, which may affect the way of economic evolvement as well as its impact on nature (see York et al. 2003). This is consistent to our assumption, that there are several possible ratios of responsibility for a current condition of an environment to accountability for current and further economic behaviour.

Adeola (1998) shows that the pursuit of a sustainable environment is not bound to a post-material condition and it is no unique feature of industrial or post-industrial societies. Hence, a sustainable environment is no distinctive luxury good—but it still has to be paid for. Because each country has a precise standing in the globalized economic system it is equipped with a mostly unique set of instruments for economic actions—and therefore with more or less limitations to execute them in an ecologically efficient way.

Clearly, the economic power at national and international scales on a globalized market is one of the most important variables influencing the human impact on the natural environment which itself is influenced by more or less strong measures depending on national and international political findings and legal solutions.

Since we do not see mono-directional constraints established by economies, politics or other kinds of social agreements, we here propose an alternative theory on environmental behaviour and success of biodiversity conservation measures: *Theory on Accountability*.

We assume that the richest countries in the world most probably have the greatest power to protect their environment and to spend money for nature conservation measures in other parts of the world. However, the same measure may be much cheaper in less developed regions than in areas of the richest countries. Furthermore, private persons and NGOs spend a lot of money to protect certain landscapes, ecosystems and species voluntarily. The so-called developing countries partially have much larger and better protected nature reserves than certain economically powerful countries.

Thus, we see a lot of work to do for most countries in the world independent of the question if these are rich or poor.

According to our theory many more environmental activities could be developed, much more money should be invested, and in developed and developing regions as well. There is no reason to wait until economies or human populations are characterized by this or that. Furthermore, economies, political instruments, legal regulations, private and voluntary investments might form coherent systems complementing one another. We here recommend to use political instruments of regulation such as taxes and subsidies. The globalized so-called free market is according to our conviction hardly able to respect requirements of the environment which are not linked to any profit.

3 Material and Methods

3.1 Data

We used indicators of economic conditions of a country and numbers related to the natural richness and endangerment of biodiversity (N = 188). Additionally, we used geographical characteristics. Most data are online available (refs. see below).

3.2 Geography

We used longitude and latitude of centroids (with and without N/S orientation), the area of the countries (in km^2), and the number of residents as geographical parameters (country related information on the internet, http://worldmap.harvard.edu/data/geonode:country_centroids_az8, assessed 12/2019). The effect of the density of the human population can also be estimated by comparison of GDP with GDP per capita.

Furthermore, we used land use data from the CIA factbook with respect to percentage values of area for arable land, the area of permanent crops, permanent pasture, forest, and others (https://www.cia.gov/library/publications/the-world-factbook; assessed in March 2020).

3.3 Economic Power, Affluence and Inequality

As proxies for the economic conditions of a country, we used the gross domestic product (GDP), mean affluence (GDP per capita), the inequality indices Gini and Palma, and GDP sectors, i.e. agriculture, industry, services (https://data.worldbank.org; assessed 3/2020, completed by information of the Human Development Report 2016 and CIA Factbook; https://www.cia.gov/library/publications/the-world-factbook; assessed in March 2020).

3.4 Natural Richness, Biodiversity, Endangerment

We used different indicators for richness, endemism and endangerment of species in a country.

The natural richness of a country is indicated by the whole number (S) of native vascular plant species, whole number of mammal plus breeding bird species, number of endemic (E) vascular plant species, and number of endemic vertebrates (excluding fish species).

As proxy for the endangerment, we extracted the whole number of critically endangered species (CR) for each country from the global IUCN Red List (2019) and additional information. A species that is critically endangered must not be restricted to a country. In contrary, an endemic species must not be threatened. As a measure for relative endangerment, we used percentage values of threatened plant species, i.e. the number of threatened plant species divided by the number of native plant species in total, and the number of endemic mammals plus birds per country which are threatened. We calculated these numbers on the basis of raw data in IUCN Red List (2020, assessed in 3/2020), based on version 12/2019 of Table 6b of the IUCN (2019), Gleich et al. (2000), Groombridge and Jenkins (2002), and a few adjustions, cf. Hobohm (2014), and CBD National Reports on the internet.

All these values can also be used as measure for the national mandate/responsibility/accountability in the framework of the Convention on Biological Diversity (CBD).

For preliminary statistics we used different combinations of all these factors. However, finally we used the number of native vascular plant species as indicator for natural richness and all critically endangered species (CR) of a country as indicator for the endangerment (response variable).

3.5 Statistics

Our statistics enable quantitative analyses on the relationship between (1) geographical/abiotic factors, (2) natural species richness, (3) economic power, (4) economic inequality, (5) pressure/endangerment of the biota, and (6) biogeographical factors.

We applied correlation analyses (Spearman and Pearson) and multiple linear regression (MLR) analyses to disentangle the complexity of the data. We also used Structural Equation Modeling (SEM) to check against less plausible correlations between variables (Browne and Cudeck 1993; Wooldridge 2003; Tabachnick and Fidell 2006; Bollen and Pearl 2013). Most variables had to be log-transformed (ln) to make skewed distributions less skewed.

For the interpretation we only used results that were congruent.

3.6 Responsibility and Potential to Act

According to the aspiration of the Convention on Biological Diversity (CBD) almost all countries in the world follow the goal to protect species from extinction. We used the economic power in combination with the pressure on biodiversity as indicator for both national responsibility and potential to develop nature conservation programmes and invest in nature conservation measures (cf. Table 3). We used the highest and lowest quartils of the variables. The economic power is indicated by GDP and GDP per capita; i.e., a powerful country is defined by both high GDP and high GDP per capita, the economic power is low if values of both indices were small.

For pressure on biodiversity we used the number of threatened plant species according to Table 6b (version 12/2019 of the IUCN Red List 2019) and/or the percentage of threatened plant species (Groombridge and Jenkins 2002, and National Reports on CBD, cf. Hobohm 2014) and/or the number of critically endangered species (CR) according to the IUCN Red List (2019, all taxonomic groups).

4 Results of Numerical Analyses

4.1 Distribution Patterns of Economic Power

Economic growth theories try to explain the success of economic activities in different countries and unequal distribution patterns of economic power on earth. Factors affecting economies, in general, are the size of a country (area, demography), recent and historical use of own and foreign resources, development of technologies, social and political factors such as the government policy and flexibility of economic markets including traffic and infrastructure, but also natural determinants such as stability of weather conditions (Anyanwu 2014; Boldeanu and Constantinescu 2015).

The distribution patterns of GDP show a high variance, due to a few very high values at its top and many relatively poor countries (highest values: China, USA,

Table 3 Predefined scheme on responsibility and potential to act with respect to combinations of economic power and pressure on biodiversity of the country

Economic power	Pressure on ecosystems and biodiversity	Responsibility and economic potential to protect nature and support nature conservation programmes and measures
High GDP and high GDP per capita	High	High responsibility at national scales (category HR)
	Low	Great potential at global scales (category GP)
Low GDP and low GDP per capita	High	Small potential at global scales (category SP)
	Low	Low responsibility at national scales (category LR)

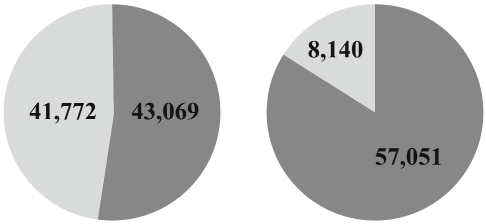

Fig. 2 Sum of GDP (left circle) and mean GDP per capita (right circle). The four richest countries (USA, China, Japan, Germany) represent a sum of GDP (left circle, right side (43,069 (Billion $) which is higher than the sum of all other 184 countries (left side (41,772). The poorest 20% of the countries (N = 38) in the sample all together produce a GDP that is about 81 billion $ per year. In contrast, each of the richest 25 (13%) countries produce a GDP of more than 518 billion $

Fig. 3 Sum of endemic vertebrate (left circle) and endemic vascular plant species (right circle) per country. Eight countries each (right sides) harbour more endemics than all other countries (left sides)

Japan, Germany). The four countries with the greatest output in total outperform all other 183 countries (Fig. 2).

The strong economic power is above average not only in absolute terms. The mean affluence (GDP per capita in $) of the 25 countries with highest values (right circle, large slice: 57,051) is more than seven times as high as the mean affluence of all other 163 countries (small slice: 8140).

This means that on the one hand, there is a group of countries with an economic output much higher than in the rest of the world, and on the other hand, there is another group of countries with a distinct higher level of affluence than the others.

4.2 Distribution Patterns of Biodiversity and Endangerment of the Biota

Species richness across the globe is highly uneven distributed as well (cf. e.g. Groombridge and Jenkins 2002).

The countries with highest numbers of vascular plant, mammal plus breeding bird, endemic vertebrate and/or endemic vascular plant species are Australia, Bolivia, Brazil, China and Colombia. These refer to the so-called *Megadiversity*

Countries (cf. Fig. 3; Gleich et al. 2000; Groombridge and Jenkins 2002; Hobohm 2014).

Assuming that the global vascular plant flora contains 236–436,000 species and assuming that Brazil and China do not share a high percentage value of their national floras, then these two countries alone may harbour 20–37% of all vascular plant species (Hobohm 2014; Hobohm et al. 2019).

Round about 65% of the countries are inhabited by 10 endemic vertebrates or less. 14% harbour more than 100 species. For endemic plants, 47% of the countries harbour less than 100 species in contrast to 12% with more than 2000 endemics.

16% of the countries with the largest numbers of endemic vertebrates are home to 10,409 or 87% of the endemics. The remaining 84% of the countries harbour 13% of the vertebrates which are national endemics (1554). 12% of the countries (22) with the most endemic plants (173,657 in total) harbour 77% and, thus, a number more than three times higher than the sum of the remaining 88% countries, which harbour 50,579 endemic plants (23%).

Threatened biota (cf. CR in IUCN 2019) show similar distribution patterns as species richness in total (see e.g., Darwin 1839, 1859; Kato 2000; Groombridge and Jenkins 2002; Hobohm 2014).

78 of 188 countries in the sample are home to less than 10 critically endangered species, while 16 countries harbour more than 100 critically endangered species each, (cf. regularly updated Tables 6–8 of the IUCN statistics on the internet). The distribution shows a high variance with a few very high values at its top (e.g., USA including Hawaiian Islands: 472, Ecuador including Galapagos Islands: 353, Madagascar: 344).

Thus, a small number of countries represent very high species richness, endemism and endangerment of their biota.

The correlations of natural richness, endemism and endangerment are highly significant. This means that countries with many species in general are home to more endemic species, and threatened species than countries with low biodiversity.

4.3 Relationship Between Economic Power and Pressure on Biodiversity

We used GDP, GDP per capita and Gini, which is strongly correlated with Palma, as indicators for the economy of a country, species richness of vascular plants in total, the number of mammal and breeding birds, the number of endemic vascular plants and number of endemic vertebrate species (excl. fish) as indicators for natural richness, area, centroids of longitude and latitude and human population as geographical factors, and the number of critically endangered (CR) species (all taxa of the IUCN Red List) as indicator for pressure to the nature (response variable). For 188 countries we got non-zero values for CR.

We calculated numerous MLR to find combinations with high adjusted R^2 and preferably low numbers of variables (cf. Hoffmann 2004).

Table 4 Results of the regression analysis with the number of critically endangered species per country as response variable, and GDP, GDP per capita and Gini as proxies of the national economy (N = 188, adjusted $R^2 = 0.434$)

Model 1	Coeff. of regression B	Standard error	Beta	T	Sign.
(Const.)	−4.924	1.305		−3.772	<0.001
ln national Gross Domestic Product (GDP)	0.338	0.030	0.698	11.214	<0.001
ln inequality (GINI)	1.802	0.312	0.329	5.776	<0.001
ln GDP per capita	−0.243	0.049	−0.307	−4.919	<0.001

Table 5 Results of the regression analysis with the number of critically endangered species per country as response variable, the number of vascular plant species (S vasc.) as indicator of natural richness, area in km^2 as geographical factor, and GDP, GDP per capita and Gini as proxies of the national economy (N = 188, adjusted $R^2 = 0.562$)

Model 2	Coeff. of regression B	Standard error	Beta	T	Sign.
(Const.)	−4.546	1.207		−3.766	<0.001
ln national Gross Domestic Product (GDP)	0.281	0.048	0.581	5.833	<0.001
ln inequality (Gini)	1.041	0.295	0.190	3.525	0.001
ln GDP per capita	−0.211	0.061	−0.266	−3.474	0.001
ln number of native vascular plant species	0.557	0.0797	0.528	7.083	<0.001
ln area	−0.152	0.038	−0.344	−4.043	<0.001

In model 1 presented in Table 4, the relationships between economic indicators and the number of critically endangered species of a country are highly significant. The contribution is declining from economic growth (GDP) to inequality (Gini), and from inequality to GDP per capita.

In this model other factors such as natural richness, area or human population which might be correlated with economic values are excluded. These are included step by step in the models 2 and 3 (cf. Tables 5 and 6).

Whenever we additionally combined indicators of the economy with variables of the natural richness, we found a positive relationship between number of critically endangered species (response variable), economic growth (GDP), and natural richness (Tables 5 and 6).

We used the number of vascular plant species as indicator of the natural richness in model 2 of Table 5, and area as a geographical factor. In this model, both the contribution of economic factors and biogeographical factors explaining the number of critically endangered species is equally high. Again, the contribution of GDP was higher than inequality, and both were highly significant.

The negative relationship between the number of threatened species and area seems to be confusing at a first glance. In general, the species number is increasing with area. This relationship is called *Species-Area Relationship* (SAR) for the whole

Table 6 Results of the regression analysis with number of critically endangered species per country as response variable, the number of vascular plant species (S vasc.) as indicator of natural richness, area in km^2 as geographical factor, GDP, GDP per capita and Gini as proxies of the national economy, and the percentage of two GDP sectors of the economy, and the area of arable land in km^2 ($N = 188$, adjusted $R^2 = 0.576$)

Model 3	Coeff. of regression B	Standard error	Beta	T	Sign.
(Const.)	−7.285	1.768		−4.143	<0.001
ln national Gross Domestic Product (GDP)	0.381	0.064	0.787	5.961	<0.001
ln inequality (Gini)	0.999	0.311	0.183	3.217	0.018
ln GDP per capita	−0.210	0.088	−0.265	−2.387	0.02
ln number of native vascular plant species	0.536	0.079	0.508	6.761	<0.001
ln area	−0.212	0.050	−0.480	−4.282	0.000
ln GDP agricult. Sector (%)	0.214	0.100	0.240	2.152	0.033
ln GDP services sector (%)	0.608	0.305	0.124	1.993	0.048
ln arable land %	−0.097	0.057	−0.112	−1.694	0.092

species number and *Endemics-Area Relationship* (EAR) for the number of endemics. Both principles have so often been varified in log-log space that the relationship has been called *Arrhenius law* (cf. Hobohm 2014; Hobohm and Müller-Benedict 2018; Hobohm et al. 2019). According to the results of the correlation analyses there is a strong and highly significant relationships between the area and the whole number of vascular plant species ($r = 0.69$), and endemic vertebrates ($r = 0.44$), and between plant richness and the number of all critically endangered species of a country ($r = 0.698$). But we have to interpret the coefficient of area ceteris paribus. Thus, the same GDP and GDP/capita generated on a smaller area will result in higher population density and therefore in higher pressure to biodiversity. A smaller GDP per capita ceteris paribus means a larger population, thus indicates a smaller population density.

To specify the importance of GDP, we also distinguished GDP sectors, i.e. GDP agriculture, GDP industry and GDP services of all 188 countries. Furthermore, we used land use parameters such as range of arable land, permanent crops, permanent pasture, and forest (in total and as percentage values) as proxies. Model 3 (Table 6) shows one of the models with a selection of these variables and relatively high adjusted R^2.

Also model 3 in Table 6 confirms the positive relationships between economic factors (GDP and inequality), population density and threats to the biodiversity.

Additionally, the model indicates the meaning of agriculture. The higher the GDP of the agricultural sector (in dollars, as percentage value) and the smaller the range of arable fields (percentage values), the higher is the pressure to the biodiversity of a country. This most likely mirrors the intensity of use of landscapes of a country.

Also the GDP services threatens the biodiversity, this however, on a lower level.

To sum up, the models presented here underline the meaning of national economies for the pressure to the biodiversity of a country. The influence of the economic growth (GDP) is higher than e.g. inequality indicated by Gini or Palma. Thus, we confirm the *Richness and Inequality Hypothesis.* Furthermore, also the natural richness of a country is relevant. The more species in a country the higher the number of critically endangered species, confirming the *Biogeography Hypothesis*. The proxies area and GDP per capita together show that the population density of a country also contributes to the pressure to nature. As a consequence we establish a further hypothesis: *Population Density Hypothesis*.

With respect to economic factors as threats to biodiversity, we did not find evidence for the *Environmental Kuznets Curve*.

5 Scope of Contribution for Biodiversity Conservation

To identify the economic potential for the development and support of biodiversity conservation programmes and measures, we compared the properties as classified in Table 1. We assume that economic richness in general facilitates a stronger contribution to the development of environmental measures and nature conservation. This view is getting further support since economic productivity (GDP) has been identified as one of the main drivers of threats to nature.

Extreme positions of the four quarters in Fig. 4 correspond to the four categories of Table 3. Table 7 represents related examples.

Most countries belong to the group of intermediate GDP and/or intermediate numbers of critically endangered species. However, we here focus on countries that are either poor or rich in terms of both gross domestic product (and GDP per capita) and number of species characterized as critically endangered by the IUCN Red List (2019).

Countries with both a relatively high GDP and high GDP per capita may easier support investments for nature conservation within or outside of their territory than other countries.

For example, Australia, Japan, Italy, Spain, Turkey, and USA belong to the countries with high GDP and high GDP per capita, in combination with high number or level (as percentage value) of critically endangered species.

On the other hand, Belgium, Saudi Arabia, Sweden, Switzerland, The Netherlands, and the United Arab Emirates (UAE) belong to the countries with relatively high GDP and GDP per capita which harbour only small numbers of critically endangered species.

We want to pronounce that our deliberations about potential and responsibility of countries represent inferences which are established on a frame of axioms and international agreements such as the Convention on Biological Diversity (CBD). We want to promote the discussion about national responsibility and investments in the environment and nature conservation. However, we do not want to dispute anyone's integrity.

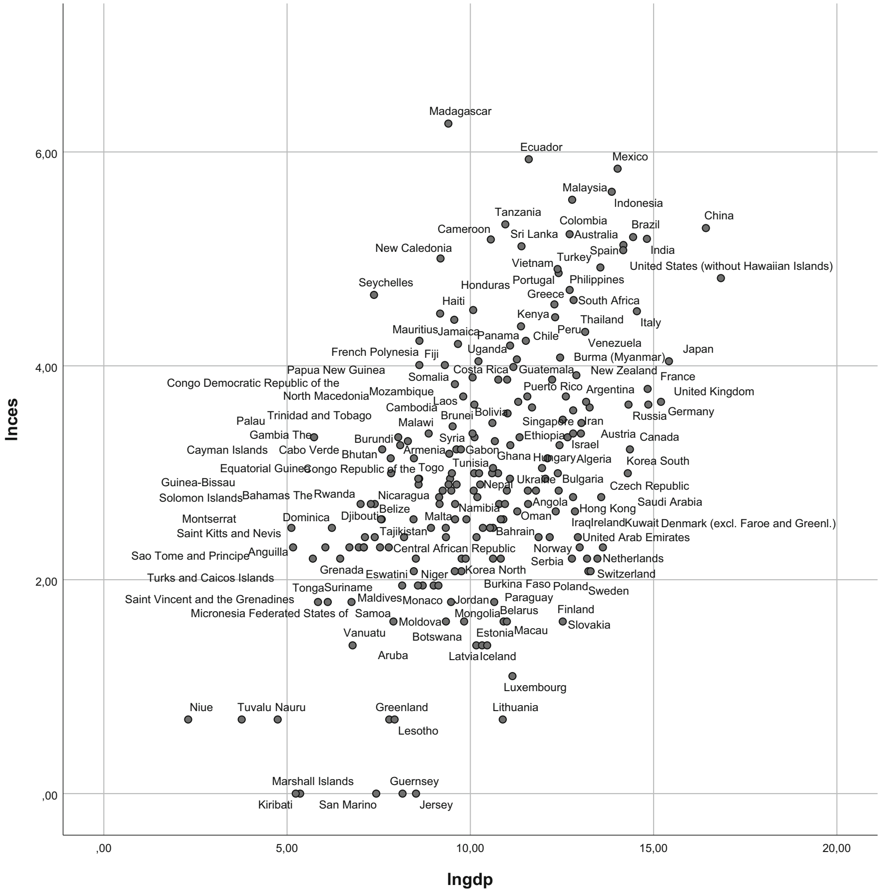

Fig. 4 Number of critically endangered species (lnces) according to the IUCN Red List of 188 countries as function of economic power (lngdp)

The systematic developed here may serve as proposal for further analyses and discussion. E.g. the use of the term *responsibility* of a country may also be interpreted and defined in different other ways.

6 Discussion

Several analyses of the relationship between economic growth, income and/or inequality and biodiversity loss, effectiveness of nature conservation programmes, area or nature reserves and/or endangered species are published (cf. e.g. Dietz and Adger 2003; Hoffmann 2004; Mikkelson et al. 2007; Clausen and York 2008; Mills and Waite 2009; Fuentes 2011; Polaina et al. 2015; Gosselin and Callois 2018; Kaur

Table 7 Examples of countries with high and low responsibility and more or less convenient possibilities to invest in the development of nature conservation measures (with respect to the order proposed in Table 1). High or low values are related to the first or last quartil of variables in both databases, respectively

Responsibility and economic potential to protect nature and support nature conservation measures	Examples
High Responsibility (category HR) High GDP and GDP per capitat, high number or level (percentage value) of threatened species	Australia, Japan, Italy, Malaysia, Spain, Turkey, UK, USA
Great Potential (category GP) High GDP and GDP per capita, small number or low level (percentage value) of threatened species	Belgium, Saudi Arabia, Sweden, Switzerland, The Netherlands, United Arab Emirates (UAE)
Small Potential (category SP) Small GDP and GDP per capita, high number or level (percentage value) of threatened species	Burundi, Haiti, Liberia, Rwanda, Sao Tome and Principe
Low Responsibility (category LR) Small GDP and GDP per capita, small number or low level (percentage value) of threatened species	Comoros, Djibouti, Kiribati, Lesotho, Marshall Islands, Mauritania, Micronesia, Niger, Vanuatu

et al. 2019). In general, most relationships are significant positive while a unimodal or U-shaped curve (Kuznets Hypothesis) often has not been confirmed.

This might have to do with the fact that the terminology of *pre-industrial, agrarian, industrial* and *service economy* is related to the numbers of workers or the amount of money of GDP by sector. However, the influences on the environment and landscapes obviously do not follow this sequence. The impact of industrial agriculture on the environment is, despite a shutdown of farms and a decreasing number of persons working in this sector in so-called *developed* countries, extremely high.

Hoffmann (2004) calculated the impact of environmental and economic influences on the number of threatened mammal and bird species. He also used cross-national data (N = 120). However, because of different predictors the models of Hoffmann's and our analyses are not directly comparable. Nevertheless, Hoffmann found that the endangerment of the species in peripheral nations are affected by GDP growth, whereas rates in semiperipheral nations are affected more by GDP per capita. Furthermore he also found an influence of other environmental factors. Mikkelson (2013) concluded that growth is the problem and equality might be the solution. Our results confirm the conclusion of Mikkelsen. Economic growth is the problem. However, equality might theoretically be part of the solution.

The variables that we have used represent numbers indicating growth of national economies, income, inequality within countries, national floras and faunas, country-endemics and critically endangered species which still live in the countries.

Independent of processes and conditions within countries, countries are connected by international legal and illegal trade across borders, sometimes over long distances. For example, illegal logging e.g. of ebony and rosewood in Madagascar is mainly promoted by the luxury market. As a consequence the pristine forests in Madagascar are declining in quantity and quality.

Many products or living individuals of species which are threatened with extinction are trafficked as medicine, prestigious objects, pets, or for other purposes.

We did not find adequate country-related indicators describing international activities directly or indirectly affecting biodiversity abroad. Thus, this aspect has to be examined for further publications.

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From Onlookers to Ecosystem-Assistants: Exploring the Potentials of Ecological Restoration Education

Mattias Sandberg and Andreas Skriver Hansen

Abstract This chapter introduces the concept and practice of "ecological restoration education" (ERE) as a novel pedagogical approach for schoolchildren. ERE combines insights from the field of "outdoor education" and "ecological restoration" and has the overarching objective of fostering learning about biodiversity through practical experience of ecosystem restoration. This chapter draws on experiences from an ERE-project in Sweden called Skolbäcken run by the Swedish Anglers Association. The aim of the chapter is to describe and discuss ERE as a potential strategy to spread interest about the importance of biodiversity and ecosystem management among future generations.

Keywords Outdoor education · Biodiversity · Learning environments · Baltic Sea · NGO · Pike population

1 Introduction

"What does education often do? It makes a straight-cut ditch of a free, meandering brook."—Henry David Thoreau.

"Is it alive?" The children from the local school flock around the shore to get a glimpse of the 63 cm long pike which is about to be released into the dark water. Victor holds the pike with one hand around the tail and the other around the belly, which is filled with eggs. It is mid-April and spawning season for pikes along the Baltic Sea coast in the Stockholm Archipelago. Victor works as an educator for the Swedish Anglers Association and has just explained to the class of 9-year-olds that the pikes are attracted by the fresh water stream coming from the flooded grasslands around which they have gathered. "It's like they are swimming against a gentle, warm breeze", he explains. When the water temperature reaches 6–8 °C, there is a

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narrow window of time for the fish to spawn before the water becomes too warm. When the spring floods ebb swiftly away again, there is even a risk that the pikes are trapped on the grassland. Continuing, Victor explains that there are about 300 female and 150 male pike in these shallow waters also referred to as the “pike-factory”. If it was not for the restoration efforts made by Victor and his colleagues, together with Värmdö municipal authorities and the World Wildlife Fund (whose main object is to attract bird-life around the wetland), there would have been no pikes here—only a straight-cut ditch surrounded by dry grass from last year. In the next part of this outdoor lesson, the children get to help Victor and his colleagues' work supporting the pike and other fish populations in the restored wetland. They carry stones that are put along the muddy banks. The ditch is thus turned into a stream again and becomes accessible for the migrating fish. In this way, the pupils take on the role of “ecosystem-assistants”, or “environmental heroes”, as Victor phrases it. “Is it alive?”, another child asks. Although released from Victors grip, the pike does not move. All is quiet. A car is put into gear on the road behind. Sea gulls are swirling above. With two gentle swishes of her tail the pike, named “Martha-Humlan” by the children, is gone.

This observation comes from an outdoor-class organised by the Swedish Anglers Association in a restored wetland in Värmdö municipal, located east of Stockholm. Through their educational project “Skolbäcken” (literally meaning “the school stream”), the association has brought several thousand schoolchildren and their teachers to sites where the association is involved in fish habitat restoration. These include lakes, streams, wetlands and coastal areas, mainly around the three largest metropolitan areas in Sweden. A characteristic feature of Skolbäcken is that the schoolchildren, beyond the role of observers and learners of fish and water ecosystems, also are encouraged to get *their hands dirty* as an important part of the pedagogy—learning about pike through actively participating in improving their habitats. In turn, these efforts might be able to help the children to not only understand nature in a generalised sense, but also as a living place (or landscape) that can be experienced with all the senses and, for better or for worse, can be altered by human activity (cf. Beery and Wolf-Watz 2014; Stenseke 2018).

2 Why Should Children Care About the Loss of Biodiversity?

Why should children care about the loss of biodiversity, and how can children get involved with practical work that concerns (re)creating and caring for different species and habitats? Several decades of environmental policies, information and education in countries such as Sweden have raised public awareness of sustainability challenges, including possible negative impacts of human activities on ecosystems and biodiversity. However, scientific knowledge about the state of world seems alone insufficient to spur people's interest and engagement.

The overarching twentieth century environmental narratives can be described as largely anxiety-based. An appeal is made, first and foremost to governments and officials, to protect and conserve the environment in order to prevent future catastrophes (Jepson 2019). Although anxiety-based narratives are justified, they also carry certain risks. They may, for example:

- Make people feel despair in relation to the overwhelming scale of the problems.
- Over-emphasise the conception of the environment as consisting of problems that must be "fixed", and therefore undermining the understanding that ecosystems will always, to some degree, be in a state of change.

Alongside this dominant anxiety narrative, there is also a parallel and growing concern that the role of people's sensory experiences and bodily interactions with nature are poorly acknowledged in environmental discourse and policy (Buijs et al. 2018; Cooke et al. 2016; Chan et al. 2016). Concerns about biodiversity are often introduced through texts, numbers and models, but not easily seen or felt in everyday life (especially everyday urban life), making issues such as disappearing species hard to relate to. In order to bring the notion of biodiversity "to life", expert knowledge arguably needs to be paired with practices and experiences that literally help give meaning in people's everyday life (West 2016). The story about the schoolchildren's encounter with the pike named "Martha-Humlan" serves as an example of one such attempt to provide children with direct and practical experiences of "nature".

3 Restoring Ecosystems and Human–Nature Relations

There are two overarching reasons for our interest in the efforts made by the Swedish Angler Association in the Skolbäcken project. The first is our interest in finding strategies that can help counteract the fast growing loss of biodiversity, which in this chapter will be exemplified by the deteriorating ecological status of the Baltic Sea. The second is our interest in reversing declining levels of interest in science amongst schoolchildren.

A grave future is painted for many coastal fish communities in the Baltic Sea, including pike (Esox lucius *L.*), due to a combination of eutrophication, overfishing, pollutants, climate changes and a decrease or change in key habitats, such as rivers and wetlands (HELCOM 2018). A main driver for the diminishing pike population is found in the disappearance of coastal wetlands (spawning grounds) due to drainage and straightening of watercourses for agricultural purposes (Engstedt 2011). Re-creating the physical structure of habitats is likely one of the most economically viable efforts that can be made to counter-act the diminishing pike populations (Nilsson et al. 2014).

A decline in interest in school science, including biology, among students in the western world has been apparent for some time (Osborne et al. 2003). This is happening parallel to concerns about children's reduced contact with and understanding of nature (Giusti et al. 2018; Skår et al. 2016). The diminishing direct contact with nature is associated with both deteriorating health and also reduced emotional affinity with the “more-than-human world” of plants, animals, different landscape types and ecosystems. Some identified barriers to nature contact are reduced access to green-blue environments, growing possibilities of virtual media, overscheduling of leisure activities, and parental and school concerns for children’s safety in public spaces (Soga and Gaston 2016).

Our combined interest in maintaining biodiversity and in stimulating children’s interest in natural science is addressed by the approach that we call “ecological restoration education” (ERE). This is a promising, yet under-explored, educational approach building on the fields of “outdoor education” and “ecological restoration”. Outdoor education aims to foster learning through the interactions between emotions, actions and thoughts, based on practical observation in different types of outdoor environment and is often based on interdisciplinary curriculum matter (Gustafsson et al. 2011). Ecological restoration can be defined as: “. . .the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (Primer; SER 2002 cited in Martin 2017).

The aim of this chapter is therefore to provide a glimpse of educational hope in troublesome socio-ecological times.

4 Introducing the Skolbäcken Project

The Swedish Angler Association, which is responsible for Skolbäcken, is a non-governmental organisation (NGO) in Sweden with over 60,000 members interested in leisure fishing. Threatened fish populations reduces the opportunities for leisure fishing, something that in turn gives incentive to protect the water ecosystems for the benefits of the fish and therefore also the members of the association. Consequently, the two main goals of the association are: (a) to stimulate interest in leisure fishing among children and youth and, (b) to support conservation and restoration of fish habitats. A distinct feature of Skolbäcken is that it integrates these two interest areas, which traditionally have been developed separately. The project was first launched in 2016 and since then, numbers of participating schools have increased following positive feedback from both children and teachers (Sandberg and Hansen 2018). Skolbäcken is primarily offered to children in grades 1–6 (7–12 years old) and is made free of charge for schools by a mix of public and private external funding.

The project is run by the educators of the association who often have a background within biology or ecology, but with a pedagogic education as well. According to the educators, the overarching objectives of the Skolbäcken project are to:

- Spur an interest in fishing and nature.
- Contribute to greater knowledge about fish and their habitats.
- Increase an understanding and will to protect and care for fish and their habitats.

An important aspect of Skolbäcken is that the association prioritises schools close to where the organisation has ongoing sites for fish-habitat restoration. The reasons for this are partly logistical; the children should be able to walk or go by public transportation, and partly formal; the curriculum emphasises the importance of fostering children's relationship to their local, nearby environments. The proximity between home, schools and the restored water also gives children the opportunity to discover a familiar location in a new light and revisit the site with friends and families after participating in Skolbäcken.

Skolbäcken shares many characteristics with traditional outdoor education arrangements. Looking at the core of outdoor education, there is a long tradition of encouraging direct encounters with different environments (Sandell and Öhman 2013). A characteristic of outdoor education is a strong focus on bodily and an experiential learning that builds on the interconnection between practical activities, emotions, thoughts and multiple sensory experiences of phenomena and places. This form of learning is often seen as complementary to the predominantly theoretical learning that is characteristic for indoor teaching. Other benefits generally associated with outdoor education include the promotion of physical activities, self-esteem, collaboration, socializing, de-stressing, tolerance and joy (Gustafsson et al. 2011). Furthermore, outdoor education is deemed suitable for an interdisciplinary curriculum and for strengthening children's contact with nature, often with the hope that emotional affinity with nature in turn leads to pro-environmental behaviour. The idea that positive experiences of nature will help to spur environmentally friendly attitudes and responsibility is stressed by the educators involved in Skolbäcken (Sandberg and Hansen 2018).

5 Different Habitats Used as Learning Environments

Skolbäcken focuses on ice, running water and wetland as three main learning environments. On the ice, the children collect and build piles of branches and twigs, which are sunk (in springtime) in order to create underwater spawning areas, mainly for perch (Perca fluviatilis). They also learn about safety issues related to being on lake ice. Running water is another learning environment and here the children put gravel, pebbles and dead wood into streams in order to create spawning areas and hiding places for trout (Salmo trutta). They also observe how fishing with electricity, for the purpose of surveying the fish populations, is carried out. In the wetlands, the so-called "pike-factories", the children watch, touch and smell the pike, which are weighed, measured and named before they are put back into the water. The restoration work consists of carrying stones, which are laid along the shoreline of the wetland and streams connecting the wetland to the Baltic Sea. This prevents the banks of the stream from eroding or collapsing, and keeps the water level high enough for the pike to migrate from the sea through smaller fresh water streams into the flooded grasslands, where they feed and breed.

In all three learning environments, Skolbäcken begins with educators contacting schools near water sites where the Swedish Anglers Association is doing restoration work. The teachers and their classes are invited for a morning or an afternoon session, usually lasting between 2 and 3 h. Prior to the visit, the teacher is sent a short instruction booklet, which introduces what will happen during the day, how Skolbäcken connects to the curriculum learning goals and how the class can prepare themselves for the day outdoors. Regardless of the learning environment, Skolbäcken consists of the following main activities: games and play; possibilities to observe and learn more about fish; small breaks; practical restoration activities. At the end of the day, the children receive a diploma and are given the title "environmental heroes" by the educators. After a couple of months, the children are invited for a return visit in order to let them know what they have achieved, and to consolidate the knowledge and experiences gained during the first visit.

6 Promising "Socio-Ecological" Outcomes

Evaluation of the Skolbäcken project has so far showed promising results and there are good indications that both teachers and children appreciate the activities and learn new things from participating (Sandberg and Hansen 2018). Below we touch upon the background and effects of restoration carried out by the Swedish Anglers Association and local municipalities, focusing particularly on coastal wetland restoration (the pike factories), before we present some experiences of Skolbäcken by children and teachers.

6.1 Ecological Outcomes

The restoration of coastal wetlands (like the flooded grassland used in our Skolbäcken example introduced in this chapter) can, together with fishing restrictions, contribute substantially to improving the pike populations in Sweden. The pike populations in the Baltic Sea use two different strategies for reproduction; they either spawn in shallow brackish water or in coastal freshwater streams. A large portion of the pike populations (including "Martha-Humlan") migrate and return to their hatching sites on flooded land (so-called "homing anadromous pike"). For these populations the loss of coastal wetlands has a severe impact. One way to counteract this is to restore wetlands and bring the water back into the landscape. Studies made of three coastal wetlands on the south eastern coast of Sweden, restored in different ways, emphasized the importance terrestrial vegetation for successful pike reproduction. In wetlands where terrestrial vegetation was temporarily flooded with shallow water, the pike larval/juvenile emigration increased from about three thousand individuals before restoration to over a hundred thousand after restoration (Nilsson et al. 2014).

Meanwhile, over one quarter of the wetland areas in Sweden have been lost due to ditching over the last 100–200 years. In some parts of Sweden, approximately 90% of the wetlands have been converted into agricultural and forest land. This is not only a problem for the pike and other fish populations. Being a top predator, the pike also play important ecosystem functions through the mechanism of "trophic cascades", as top-predators help regulate other fish communities in the ecosystem. Studies made in lakes have shown the importance of predators like pike in regulating zooplankton-feeding fish, which in turn can improve water quality levels in terms of clearer water and fewer algal blooms. There are studies suggesting that these relationships also operate in marine environments, and that the increase of pike in the Baltic Sea might mitigate severe problems with eutrophication (Engstedt 2011, p. 14 with reference to Carpenter et al. 2001; Persson et al. 1999, Spens and Ball 2008; Frank et al. 2005; Scheffer et al. 2001). Notwithstanding the efforts made with restoring coastal wetlands, the situation for the coastal pike populations in the Baltic Sea coast is still far from sustainable.

Wetland restorations, meanwhile, also have direct important effects for counteracting eutrophication. Wetlands increase the retention time of water, which in turn means that nutrients from fresh water systems are denitrified or incorporated in freshwater primary production instead of ending up in the sea (Nilsson et al. 2014). Furthermore, wetlands are some of the most diverse and species-rich biotopes that exist in Sweden, hosting many types of vegetation and a large variety of amphibians and insects, the latter being a source of food for other fish, birds as well as other species. About 19% of red-listed species in Sweden are connected to wetland habitats, and 11% directly depend on wetland areas for their survival (Naturvårdsverket 2019).

6.2 Learning Outcomes

Recently, the learning and inspirational outcomes of Skolbäcken have been evaluated on the basis of observations of three school classes and follow-up interviews with children and educators. The follow-up interviews, which took place about a month after the day in the field, were made with two of the classes (9–10 years old) that we observed (one class visiting the wetland/the pike-factory, and one class visiting the ice). The schoolchildren were interviewed only once and in smaller groups with a mix of boys and girls. The interviews were recorded and transcribed. The observed class (7 years old) visiting running water did drawings of their day by the water, instead of being interviewed, and thereby also got a chance to evaluate their experiences of the different activities during the day. The educators were interviewed both during and after the day outside. The results from the evaluation indicates that schoolchildren have strong memories of their visits and can recall the fact-based information given by the educators concerning life of fish and the understandings of basic ecosystem structures and functions (Sandberg and Hansen 2018). The observations, one class visiting each of the different learning environments introduced above, reported great joy and enthusiasm associated with the practical activities in Skolbäcken. The children enjoyed carrying heavy stones and showing personal strength, running with spruce branches across the lake ice and throwing stones into streams, all during school hours!

Teachers were found to particularly appreciate the engagement of the educators representing the Swedish Anglers Association, especially because of their shared passion for the topic. The teachers also welcomed the possibility of combining several different school subjects, including biology, physical education and health, geography, maths, history and language. In follow-up interviews, one teacher highlighted the challenges involved in promoting outdoor education by emphasising how a large proportion of her teaching time is devoted to preparing for national tests (Sandberg and Hansen 2018). In this context, the opportunity to spend time outdoors and share pedagogical responsibilities with the educators was particularly welcomed.

Whether Skolbäcken heightened the children's awareness of, and engagement in, fish habitats and their protection (one of the motives for running the project), is more difficult to ascertain. By participating in restoration work, the children engaged with their local environment in a manner that was different from what they are used to during school hours or with friends and family. However, in the follow-up interviews, the impression was that the children have a rather unsentimental attitude to their own contributions in assisting the pike populations. It seemed fun to help out, but perhaps no more than that. It appeared that the children may not ascribe value to either was being said (although they were able to recall most of the information), or to being assigned the role of "environmental heroes" (Sandberg and Hansen 2018). Further studies on this are required.

7 From Skolbäcken to "Ecological Restoration Education"

We argue that the explicit focus on ecological restoration as a teaching method sets Skolbäcken apart from many other outdoor education programs in Sweden. We call this promising pedagogical approach and method "Ecological Restoration Education" (ERE). There are several contemporary and historical examples of schoolchildren doing gardening, tree-planting and picking litter etc. from around the world (e.g. Kardell 2004; Cruz and Segura 2010; Cramer 2008; Knackmuhs et al. 2017). However, these examples are often small in scale, poorly documented, and with a few exceptions, one-off projects. Overall, then, the ERE initiatives appears to hold great promise, but there remains a need for further conceptualisation and evaluation.

As mentioned earlier, ERE is an amalgamation of "ecological restoration" and "outdoor education". While ecological restoration has a long history in practice, the concept itself was not commonly used until the foundation of the Society for Ecological Restoration in the late 1980s. Ecological restoration is commonly defined as: ". . .the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Primer; SER 2002 cited in Martin 2017). Within academia, ecological restoration aligns with conservation biology and more recently also the idea of rewilding, with a focus on protection of valuable ecosystems and restoration of natural habitats (Pires 2017).

The field of ecological restoration has been criticized for deploying a naïve and static understanding of nature. While nature is inherently dynamic, as studies of climate history have revealed, an ecosystem can never be restored (in the true sense of the word) into a previous condition, only altered (Choi 2007). Ecological restoration inevitably involves values, ethics, priorities and, most importantly, human actions in the landscape. As such, it is a field that depends on insights both from the natural and the social sciences, as well as direct involvement of actors who live adjacent to and/or depend directly on the health of the ecosystems (Palmer et al. 2016). The questions of *who* decides *when* an ecosystem is deemed *degraded*, and how restoration should be done, make ecological restoration an inherently political issue (Martin 2017). This observation also relates to the question of *which actors* should be responsible for the restoration, as there are often differences in ideals between different actors (Blicharska and Rönnbäck 2018).

The prospect of fostering engagement with fish, fishing and water ecosystems is an explicit driver and goal for the Skolbäcken project. There is evidence in the literature of a connection between nature experiences and memories in childhood and pro-environmental behaviour and engagement later in life (Beery and Lekies 2018). However, it is important to acknowledge that this connection is often found to be modest and that there are several challenges when trying to empirically study such relationships (Beery and Wolf-Watz 2014). Firstly, there are many ways of being environmentally engaged and so defining and operationalising this term is difficult. Secondly, it is difficult to weigh the importance direct nature contact has in relation to other experiences and sources of inspiration during childhood, such as norms and encouragement from families and friends. Third, "nature" is a very broad concept—from the flora of bacteria in our stomachs to the stars above our heads. It is therefore difficult to say something specific about these myriads of different phenomena and how they can help form children's values and behaviour.

Finally, the concept of ERE can be seen as a part of larger movement that stresses the importance of seeing humans' role in nature in an alternative, more positive and constructive light than in anxiety-driven narratives. Jepson has suggested "the Recoverable Earth" as a narrative, which "offers citizens something new, hopeful intriguing, purposeful and potentially rewarding, namely the invitation to participate in the unfolding new stories about the relationship between nature and people" (Jepson 2019, p. 128). We see concurrence between Jepsons assertions and the unfolding of ideas and practices behind the development of Skolbäcken.

We are fully aware that in the era of gloomy environmental prognosis, any hopeful position about the recoverability of the world and humans active role in it can easily be deemed romanticised and unrealistic. To make our hopeful position a bit more robust, we frame it as "meliorism". This is a position that takes a middle ground between fundamental optimism and pessimism and is important within the pragmatism tradition and philosophers such as John Dewey (known in the context of education for the phrase "learning by doing"). In short, meliorism entails a trust in the possibility of humans' ability to improve the world through knowledge and collaboration, step-by-step, evaluating and improving situations as they unfold (Metzger 2018).

8 Concluding Remarks: From Onlookers to Ecosystem Assistants?

What happens in outdoor education when we turn children from "onlookers" to "ecosystem assistants"? In this chapter, we have discussed the role of direct encounters and sensory experiences in fostering children's understanding of and interest in biodiversity. We have introduced the Skolbäcken project as an example that brings the global and vast problem of biodiversity loss into the realm of children's experiences and reach—here illustrated by children giving a nickname to a 63 cm long pike migrating towards her spawning grounds on a cold April morning. The encounters between schoolchildren and the pike at the restored wetland are arranged with the hope of helping children understand ecological relationships and their own potential role in improving them. We call this combination of outdoor education and ecological restoration Ecological Restoration Education. We identify ERE as a promising concept and practice, albeit one that requires more research attention in order to better understand its potential socio-ecological effects.

We believe the idea of fostering "nature encounters" is an important point of departure if one wishes to stimulate children's interest in and relations to other species and to "nature" in a wider sense. Within the field of human geography, the notion of encounters has been discussed in terms of "meetings where difference is somehow noteworthy" (Wilson 2017, p. 464). Wilson particularly stresses the "transformative capacity" of encounters that for better and worse always, and in myriads of more or less predictable ways, make "[a] difference". In an educational setting such as Skolbäcken, this entails openness to what encounters, such as the one between the children, the pike and the wetland, might lead to. Encounters can be anything from enlightening, frightening, surprising and boring, but never *meaningless*. In the case of Skolbäcken, the encounters between children, the habitat/landscape and pike inevitably make a difference for all the involved parts: in the children's experience, in the configuration of stones and water flows, in the possibility of pike to spawn, etc. Exactly where this 2-h encounter in the wetland has taken the children and pikes is (still) unknown. Life is full of ambiguity and surprise, and the encounter with "Martha-Humlan" may have awoken more feelings and commitments in the children than was apparent in their responses to the evaluators. We believe that there are plenty of good reasons to stay attuned to encounters, in whatever shape they appear.

Finally, we think that Henry David Thoreau, who was quoted in the beginning of this chapter, would have agreed with us that true education has much to gain from supporting meandering brooks, in a playful manner, *together with children*.

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Part III
Perspectives, Predictions and Solutions

What has to be done to protect the species on Earth?

What is the meaning of human influences on ecosystem types for the survival of the biodiversity?

Where and where not might the idea of wilderness and the reduction of human activities be the best solution?

In this section we focus on the future and realistic options to manage habitat types, food webs, specific assemblages, and to reduce the pressure to endemics and critically endangered species.

We identify change and intensification of land use as greatest problem for species conservation. As a consequence, we recommend concrete nature conservation programmes, alterations of regulations and specific education and monitoring systems.

Distribution and Habitat Affinity of Endemic and Threatened Species: Global and European Assessment

Carsten Hobohm, Michaela Moro-Richter, and Carl Beierkuhnlein

Abstract Realms of species, assemblages, and whole ecosystems are threatened by human activities such as damage, resource use, pollution, introduction of neobiota, and also by natural processes and disasters. We present an assessment of distribution patterns and numbers of endemic and threatened species with respect to their habitat affinity and threats at global and European scales.

We used five databases for analyses: *IUCN Red List of Threatened Species* (2018, 2019a, b, c), *European Red List of Habitats* (Janssen et al. 2016) including fact sheets, *Plant Endemism Assessment of Red List Habitats in Europe* (PEARL), *Endemic Vascular Plants in Europe* (EvaplantE), and a global *database on hyper-endemics* (Hypedata). The first two are available on the internet, the latter are own databases. Hypedata is taxonomically and geographically not restricted, PEARL and EvaplantE are focusing on the situation of vascular plant species in Europe.

The categorization of habitat types is necessary to get a classification scheme and a quantitative relationship with respect to the meaning of habitats for endemic and threatened species. Furthermore, such definitions and categorisations are helpful to describe consequences in environmental politics and management. Thus, the first part is related to classification and definition of habitat types which is predominantly in accordance with the highest level of other classification schemes.

We here introduce the term *hyperendemism* in the ecological-biogeographical context. *Hyperendemics* are taxa with an extremely small range (<1 km^2) or a very small population size (<50 mature individuals). The list presented here is just the kick-of of processing a database.

At the moment the list represents 551 species, i.e. 494 plant species (482 vascular plants, 10 bryophytes, 2 lichens), 56 animal species (41 vertebrates, 15 invertebrates), and 1 fungus.

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355 hyperendemic species live on islands, 196 on mainland including mainland of Australia.

Many hyperendemics are assumed to be remnant populations of species with a much wider range in the past. Some are identified as neo-hyperendemics that evolved during the late Pleistocene or early Holocene, and simply have not been able to enlarge their range, yet.

Because of the limited range of occurrence or population size the survival of hyperendemics and local endemics should have highest priority. Therefore, any risk including the probability of introduction of alien species, pathogens and biological tourism should be minimized. On the other hand, measures to enlarge the populations and safekeeping of genetic material should systematically be planned, organized and intensified, for example with support from botanical gardens, seed banks, zoos and aquariums.

General needs and consequences for different habitat types can only be specified very broadly. Thus, the consequences delineated here may serve as a basis for discussion and should be assessed in every case at local to regional scales.

Forest, shrubland and freshwater habitats harbour most critically endangered species on Earth. However, the importance and endangerment of habitats and associated species differ considerably from region to region. For example, in Europe and Central Asia habitat types of open and semi-open landscapes harbour much more endemic and threatened species than forests.

Globally, agriculture, land use change, forestry, and biological resource use are the most threatening factors for biodiversity. Many terrestrial ecosystems are directly and indirectly affected e.g. by conversion, tilling, plantations, construction of roads and buildings, and intensification of use, including increasing effects of physical, chemical and biological processes.

In general, the risk of invasive species from abroad for the survival of native species is higher where alien species represent niches which have not been occupied before, and is increasing with the introduction of hitherto not represented functional roles (e.g. predators). Thus, many bird species on islands became extirpated by introduced animals such as rat, cat, goat, snake or others simply because the native and often ground-breeding birds have had no experience with such aggressive predators in their evolutionary life before. In all these cases competition was not the problem but the representation of a new node in the food web. Therefore, the situation on islands has to be assessed and evaluated in a different way compared to most mainland regions. Across Europe, for example, no native species became extinct because of the introduction of an alien species.

For hyperendemics invasive and other problematic species, genes and diseases are the most important threat category.

Climate change and severe weather might especially be relevant in combination with other threats.

In general, threats and the composition of endangered species differ with respect to habitat type. Thus, also consequences and recommendations have to be specified with respect to locality, habitat type and target species.

For the survival of critically endangered species it is extremely important that the range of protected habitat types should be enlarged. According to different recommendations of environmental organizations the protected area of all habitat types should exceed the 10% level at regional and global scales. In many cases, the protection of the diversity of habitat types at the landscape scale is the best measure to preserve species diversity. For protecting all species on Earth this alone, however, would definitely not be enough.

Keywords Endemism · Threats · Habitat classification · Seed banks · Botanical gardens · Zoos · Aquariums · Global assessment · Europe

1 Introduction

Many species in different regions of the world are threatened with extinction. Due to their evolutionary history and ecological requirements they are more or less strongly connected to specific regions and habitat types.

The purpose of the analyses is to find out where in the world and in which habitat types threatened species are concentrated. Furthermore, we want to quantify the threats in relation to numbers of threatened and endemic species. For example, how strong is the impact of climate change in comparison with land use change?

For such a quantification scheme it is necessary to classify the habitat types in the first instance.

2 Material and Methods

2.1 Habitat Classification

An uncountable number of scientific definitions for terms such as *forest*, *swamp*, or *grassland* exists. For example, forests are normally characterized by woody plants (timber) with a height of at least 5 or 10 m and a minimum tree crown cover of 10, 30, or 50%, respectively (see different FAO definitions on the internet). Also the characteristics and limits of *tropical rainforests* have been defined in different ways with respect to latitudes, climate classification, mean temperature, temperature of the coldest month, precipitation rate, length of the dry season, structure, height, diversity of tree layers, specific biological characteristics, and other aspects.

Why should it be important to define habitats or ecosystem types? People normally know what a *river*, a *forest* or a *coastal dune* is. What is the problem if a certain vegetation type in SW Australia is called *swamp* and the same would be defined as *wet heath* by somebody else? How exact should such definitions be? What is their impact on legal or political processes?

On the other hand, how should it be possible to compare the proportion of protected forest area in two countries and the responsibility of forestry ministries if different definitions are used? The exact determination and characterization of habitats and ecosystems is important whenever we talk about ecology, biogeography, species compositions, laws that are linked to activities in the landscape or nature conservation measures.

As comprising term for categories such as forest, swamp or heathland in this contribution we prefer to use *habitat types*. The terms *ecosystem*, *habitat* and *community* are particularly used for the same section of a landscape or sea region. However, the view is slightly different. The term *ecosystem* has a focus on energy and material reservoirs and fluxes, on ecosystem functions and ecosystem services which include benefits for humans. *Habitat types* are units with a typical structure and species composition. The *community* today is related to the living part of a habitat or ecosystem. According to Chiarucci (2007, 214) "*A plant community is formed by all the plants living in a given unit of space and time*". Analogously, a *community* with all inhabitants is formed by all organisms in a given unit of space and time. With respect to the references cited, the term *habitat*, *habitat type* (abstract unit) and *habitat group* (formation) are preferably used in the following.

Classification schemes of ecosystem, habitat or community types are often based on species composition, structure, climate, soil and other ecological criteria (Faber-Langendoen et al. 2012; Jennings et al. 2009; Mucina et al. 2016, see also the regularly updated classification for European ecosystems of EUNIS, the Red List of European habitats, and the IUCN Red List on the internet). We here consider EUNIS (Davies et al. 2004) which is predominantly in accordance with the Red List of European habitats (Janssen et al. 2016) and the habitats as defined by the IUCN Red List (IUCN 2018, 2019a, b, c). In this chapter only a few adjustments with respect to other classification schemes are applied.

A species can be *rare* in a region even if it is widely distributed. It can be *endemic* (restricted) to a certain region and in the same time be non-endemic to another region, e.g. a smaller one.

The term *endemism* refers to species that exhibit a clearly limited spatial distribution (Hobohm 2014). Even if the fundamental understanding of endemism refers to a spatially limited area, evolution of species and their population dynamics and dispersal takes always place within a given environment including abiotic conditions (e.g. resources) and biotic interactions (e.g. mutualism or competition).

Threatened species often suffer from human pressure and/or changing environmental conditions. However, not all endemics are threatened and threatened species are often dispersed across large regions (IUCN 2018, 2019a, b, c).

Both, rare and endemic species are often vulnerable or threatened to become extinct, for example due to changing environmental conditions.

Species with extremely limited areas have an outstanding value in nature conservation (Hobohm 2014). Such species are frequently protected by law. Various management activities are undertaken in order to ensure their survival. Such species are underrepresented in data bases not only because of their limited occurrence but also to avoid exploitation, damage and/or biological tourism. Research on endemic species that often exhibit only few individuals is scarce. And in consequence, the mechanisms that are responsible for *hyperendemism* are not well understood.

We here introduce the term *hyperendemism* which is related to taxa with an extremely restricted biogeographical range or a very small population size.

Today, the term *hyperendemism* is used in the context of medicine and diseases (cf. e.g. Leach 2008). We here advocate using this term also in the context of biogeography, ecology and nature conservation. With increasing knowledge in phylogenies, taxa and species distribution and with increasing pressures on natural populations, there is a growing demand to label species that are likely to be threatened due to their low abundance and strongly limited area of distribution.

Hyperendemic taxa exhibit an extremely restricted and narrow distribution. It would be appropriate to define a specific range size for hyperendemics such as one square kilometre. Dependent on the size of organisms, their life cycle and dispersal capability, distribution areas of hyperendemics may differ in size. In the case of mobile animals such as birds, the home range or breeding ground may serve as an appropriate scale.

For many groups of animals, it is simply impossible to determine exactly their distribution range as they migrate and the range is more or less flexible. If population size is small, it may become feasible to record or calculate its number of individuals. Such small populations may also be spatially restricted, but this is not necessarily the case. The Javan Rhinoceros (*Rhinoceros sondaicus*) has been widely distributed in forests across the island of Java and also in Vietnam but today the population size is 40–60 on Java and maybe 5 in Vietnam (IUCN 2019c).

Thus, we also take species with small populations into account. Since the IUCN has categorized taxa as critically endangered if the population is smaller than 50 individuals (category CR, criterium D) we adopt this categorization and call the relating species hyperendemics as well.

The concept of the *micro hotspot* was most probably introduced by Fenu et al. (2010). This study focused on vascular plants on the island of Sardinia. Fenu et al. labelled a mountainous part of the island with a high concentration of endemics as micro hotspot. Grant and Samways (2011) used the term micro-hotspot for important subareas in protected areas. They analysed distribution patterns of insects (Odonata) within a biosphere reserve and distinguished buffer zones, transition zones and micro-hotspots.

Isolated environments such as springs that are substantially different from their surrounding habitats serve as habitat islands for endemic species. Hershler et al. (2015) analysed the assembly of the gastropod fauna of an isolated spring in southern Nevada. They identified endemism patterns and described a new species and labelled this spring a micro-hotspot, too. However, in one case there is a gradual increase of endemism with elevation and in the other case there is a clear limit between the extraordinary habitat and its surrounding. Nevertheless, in both cases, those species that share a spatially limited distribution in a micro-hotspot are restricted to this due to ecological constraints.

The sensitivity of such populations to eradication explains the need of species conservation management. For this reason, the term micro-hotspot is an adequate label for small areas with narrow ranges of endemic species. In this sense all areas with at least one hyperendemic species or subspecies might also be designated as micro-hotspots, where hyperendemism is the trait and micro-hotspot is the spatial correlate to it.

Hyperendemic species can result from declining populations, local extinctions within the former range of distribution. In this case they can be understood as remnant populations. Such remnant populations that experience a severe decline of individuals are likely to have lost genetic diversity within the entire species (Price and Hadfield 2014).

Small spatial ranges as a result of declining populations may be caused by natural processes such as volcanic eruption on an island. However, human pressure such as land use change, fragmentation, introduced herbivores, predators or diseases seem to be a major contribution to habitat loss and hyperendemism today (IUCN 2019c).

Hyperendemics can also emerge from recent speciation. Neo-hyperendemics result from recent speciation processes, e.g. apomictic species such as members of the genera *Hieracium* or *Sorbus* across Europe (Gregor 2013).

Concerning palaeo-hyperendemism, species evolved long-time ago but have not managed to extend their distribution area or the range decreased over time. Here, species with very specific habitat requirements can be listed. In some cases of old phyla it is difficult to find out if this species has been more widespread in the past (e.g. *Wollemia nobilis*, cf. Woodford 2000).

In cases of occasional very distant populations, fake-hyperendemics have been temporarily created by scientists. An extremely small population of a *Marsilea* species was considered to be a hyperendemic species when it was recorded for the first time on the Azores. Later on it was identified to belong to the Australian species *Marsilea hirsuta*, a fact that was not to be expected because it is unlikely for plant species to disperse across hemispheres and oceans. Thus, not only the former species name of the Azorean population became invalid, the label of the species changed from native with high conservation priority to an introduced species with low conservation value (Schaefer et al. 2011). This illustrates that categories are dependent on the respective state of knowledge.

A short version of the preliminary list of hyperendemics is represented in the Appendix.

Through direct and indirect impacts, humans have modified habitats for species in all biomes but with differences in intensity and effect size. Habitats are subject to land use, degradation, pollution and even complete destruction. Resources were exploited, alien species were introduced, nutrients were added, soil eroded, trophic cascades were disrupted.

Here, we relate patterns of endemism and threatened species to habitat types of global importance. In order to generalize as well over specific and local conditions as to cover a broad range of ecosystems we classify major habitat types for species. For the characterization of habitats we used different classification schemes, and tried to find a clear description and definition (cf. e.g. Davies et al. 2004, Janssen et al. 2016), IUCN Red List 2018, 2019a, b, c).

2.1.1 Range of Habitat Groups

Also to date it is difficult to find reliable numbers for the global range of different habitat types. Table 1 contains data of different sources, definitions and modes of calculation. It shows the partitioning of the surface of the Earth with respect to large groups of habitat types. However, these numbers serve as a first orientation because it can not be guaranteed that different authors and sources have used the same classification scheme.

The range of desert, arable land, urban and artificial habitats is currently increasing. The range of grassland, shrubland, glaciers, and active floodplains is decreasing while the range of the deeper ocean, rocks and screes, and intertidal habitats is remaining more or less constant. There is some discussion about the tendency of the whole range of forest. However, this dispute relates to the use of deviating definitions of the term "forest". The area of forest clearly declines in large areas of S America, notably in Brazil, and in tropical and subtropical regions of Africa and Asia while the range in Europe is increasing. There is another discussion about the range of coastal habitats in the face of rising sea level. However, we assume that the quantity of coastal sediments during the last 30 years was slightly increasing (Donchyts et al. 2016), and that typical habitats such as dunes and salt marshes are decreasing because of anthropogenic damage and conversion.

Recent trends most probably will continue for the next years or decades. The categories of habitat types are used as follows for further numerical analyses.

2.1.2 Marine Habitats

Marine habitats or ecosystems are water bodies and substrates directly connected with the ocean. Marine waters are normally fully saline, exceptionally or in transition zones brackish or almost fresh, like for example in the northern part of the Baltic Sea with very low salt concentration.

The neritic parts are shallow waters of the shelf oceans between c. 200 m depth and low tide (e.g. Fig. 1).

Marine ecosystems at high latitudes include bodies of swimming ice. Marine benthic (related to soils) and marine pelagic (water bodies) ecosystems can be distinguished.

The low tide level in this classification scheme roughly marks the border between marine oceanic and marine intertidal ecosystems. Subtidal seagrass beds, for example with *Zostera marina* (ssp. *marina*) in the Baltic Sea are grouped within the marine oceanic environment whereas seagrass beds with *Zostera marina* (ssp. *angustifolia*) and *Zostera nana* living on tidal flats of the Wadden Sea area characterize the transition zone between sea and land and are part of the intertidal ecosystems which here are grouped within the *coastal and saline* habitats.

Table 1 Global range of habitat types (percentage of cover). The area of the whole surface of the Earth is given as 510,000,000 km^2. The numbers may serve as approximation since the sum of percentage values is not exactly hundred. Note that percentage values are related to the surface of the whole Earth (declining order)

Habitat types	Area in km^2 (% of the surface of the Earth)	Quantity (range increasing or decreasing)	References (and explanations)
Marine oceanic and deep benthic	329,640,970 (64.6%)	Constant	Harris et al. (2014) (whole ocean surface minus area of shelf sea)
Forest	38,910,364.5 –41047898.11 (7.6–8.0%)	Decreasing in many parts of the world, increasing in Europe	FAO (http://www.fao.org/faostat/en/#data/RL; assessed 3/2019, own calculation based on numbers of CIA (2018, 2019)
Grassland	35,850,720 (7%)	Decreasing, conversion to arable land and tree plantations still continuing	Dixon et al. (2014) (area of permanent pasture acc. to numbers from CIA (2019) 38,553,418.8 km^2 or 7.6%; however, these may also contain heathlands and scrub)
Shelf Sea (marine neritic)	32,242,540 (6.3%)	Slightly increasing with rising sea level	Harris et al. (2014) (low water line to a depth at which there is usually a marked increase of slope towards oceanic depths)
Barren and sparsely vegetated land	27,520,000 (5.4%)	Area of rocks and screes constant, desert increasing	FAO (http://www.fao.org/faostat/en/#data/RL; assessed 3/2019)
Shrubland	16,273,417 (3.2%)	decreasing	FAO (http://www.fao.org/faostat/en/#data/RL; assessed 3/2019)
Arable land	14,237,944–14, 980,979 (2.8–2.9%)	Increasing	FAO (http://www.fao.org/faostat/en/#data/RL; assessed 3/2019), own calculation based on number from CIA (2019)
Continental Glaciers	13,850,000 (2.7%)	Decreasing ice mass and area declining at a small rate	Likens (2009), Velicogna (2009)
Urban	4,468,173 (0.9%)	Strong increase caused by growing population and migration into cities	Liu et al. (2014) (including horticultural land and other habitat types in cities)
Inland water bodies	4,445,700 (0.9%)	Unclear trend (active floodplains decreasing)	FAO (http://www.fao.org/faostat/en/#data/RL; assessed 3/2019)
Permanent crops	1,639,619–1,685, 428.17 (0.3%)	Increasing (?)	CIA (2018), and own calculations based on numbers in CIA (2019)
Marine intertidal, coastal, supratidal nearshore	124,286–131,821 (intertidal; 0.02–0.03%)	Slightly increasing area of nearshore terrestrial land despite rising sea level	Values for intertidal habitats according to Murray et al. (2018), increasing area of coastal regions according to Donchyts et al. (2016)

Fig. 1 Marine farming (algae) near Paraty, Brazil, Atlantic Ocean

2.1.3 Coastal and Saline Habitats

Coastal habitat types include intertidal and supratidal habitats, such as seagrass beds (p.p.), saltmarshes, coastal reeds, coastal and maritime sands (Fig. 2), beaches, dunes, coastal dune valleys, coastal rocks and cliffs, maritime heath, unvegetated saline soil, and inland salt steppe. We here include inland salt steppe in this group of habitats because these often harbour very similar compositions of species in comparison with the coastal saltmarsh. And we exclude forest on coastal dunes. Coastal dunes covered by forest are in general more related to inland forest than to sparsely vegetated, grassy or shrubby coastal dunes.

Mangroves and saltmarshes dominated by scrub vegetation are included because they are almost completely different from other scrub or forest types which are located more inland.

For distinction of coastal and inland rocks and cliffs it is necessary to analyse the species composition. Many of the typical coastal communities do not show any direct connection to saltwater or salt spray. In this case the humidity and marine buffer of temperature extremes might have an additional influence on the species composition.

2.1.4 Freshwaters Habitats

Standing and running waters such as lakes (Fig. 3) and rivers, including ponds, minerogene springs, wet streamsides, river-banks, margins of pools, seasonally

Fig. 2 Beach of tephra at the Pacific coast of Kamchatka, Russia, NE Asia, with *Mertensia maritima* in the foreground

Fig. 3 Lake Prespa, a very old tectonic lake, shared by Albania, Greece and North Macedonia

flooded ground and periodically dry pioneer-vegetation on river-banks, streamsides, river banks, lake margins belong to this group of ecosystems.

Artificial or constructed inland waters such as canals which support a semi-natural or natural community with typical species are included. Seasonal dry parts of rivers and lakes are transition zones to other ecosystems. The classification in this case depends on the length of the dry season and similarity of assemblages.

During wet seasons when the ground is inundated the habitats and species compositions in many cases belong to this type of ecosystems. During dry periods they may be covered with pioneer vegetation as a transition to reeds, ruderal habitats or other ecosystem types.

Another transition zone is the mouth of a river in connection with the marine environment. The border may be defined by the species composition or concentration of salt.

2.1.5 Mires, Bogs, Fens and Swamps

Swamp-springs, mossy springs, moors, damp marshy ground, bogs, swamps, reeds, peaty soils with typical vegetation—other than e.g. plantations—belong to this group of ecosystems. Many but not all types have organic material at the bottom of the ground. The ground is wet for half of the year or more. Waterlogged ecosystems with frozen groundwater are included. Inland saltmarshes and the water body and rock structure of springs and waterlogged ecosystems dominated by trees or large shrubs are excluded. Also wet forests with organic layers at the top soil are excluded and included in forest or woodland.

2.1.6 Grassland

Landscapes dominated by grasses and herbs (Fig. 4), sometimes by lichens or bryophytes, including e.g. pastures and meadows, grassland-connected fringe communities, herb vegetation of the alpine zones, subalpine megaphorb communities, and inland dunes e.g. with *Corynephorus canescens*—grey dunes—are typical for this type of ecosystems. Also steppe and dry or moist savannas which have a tree cover of less than 10% such as Campo Limpo and Campo Sujo (Cerrado, Brazil) are included. The vegetation cover normally exceeds 30%.

Reeds, fens, coastal dunes covered with grasses such as e.g. *Ammophia arenaria* or heathland with *Calluna vulgaris* or *Empetrum nigrum* (white and brown dunes), cropland and inland saltmarshes even if these are dominated by Poaceae or Cyperaceae are excluded.

Fig. 4 Species-rich meadow in Slovenia, Central Europe, with *Melampyrum carstiense* (red) and *Rhinanthus aristatus* (yellow)

2.1.7 Heathland and Scrub

Ecosystems such as Matorral, Garigue, krummholz, sclerophyllous scrub, Kwongan (Fig. 5), Fynbos, Cerrado, Caatinga, dominated by woody and/or stem-succulent plants, including wood-margins, hedges, heath, bushy places, and openings in woods (p.p.) belong to this group of ecosystems. The vegetation cover is greater than 30% and the vegetation is dominated by species that typically do not exceed 5 m maximum height. Single trees may occur.

Different but not all types of tundra are included here. Grassy tundra, Campo Limpo and Campo Sujo (Brazil) are excluded and included in *grassland ecosystems*. Tundra with sparsly vegetated ground is also excluded and included in *desert and rocky ecosystems*. However, many types of tundra and savanna are dominated by dwarf shrubs or shrubs and are included here.

2.1.8 Forest and Woodland

This type of ecosystems includes dark and open forest, woodlands such as Cerradao in Brazil, and forest plantations. Riverine and swamp forest are included. Savannas which have a tree cover of more than 10% are also included, but no plantations of apple trees, olive groves, and other tree plantations that are part of the agricultural land. Mangroves are also excluded as they normally are formed by species with a shrubby habit that do not reach a height of 10 m.

Fig. 5 Fire-prone Kwongan ecosystems in SW Australia with *Xanthorrhoea preissii*

The trees should be able to reach a height of 10 m also under very poor nutrient conditions. Trees normally have a single stem in contrary to shrubs. Also this feature may help to distinguish woodland and scrub/shrubland.

2.1.9 Desert and Rocky Habitats

Inland rocky places, calcareous cliffs, rocks, rocky and stony ground, unvegetated, barren and sparsely vegetated ground, rocky hillsides, screes, alpine moraines, stony slopes, rock-crevices, desert (Fig. 6), and caves are included in this type. Also glaciers and sparsely vegetated moraines of the terrestrial land belong to this group of ecosystems. The vegetation cover is normally much less than 30%. Deserts have been classified e.g. by precipitation and vegetation cover. We here follow the general trend to define sparsely vegetated habitats with less than 5% cover as desert, and between 5 and 30% as semi-desert. For relating moraines, screes and other rocky habitats the terms *desert* or *semi-desert* are normally not used.

Coastal rocks with a typical—*coastal*—species composition between 0 and 200 m asl. are excluded and included in coastal ecosystems even if they are not directly influenced by salt water and even if the vegetation cover is less than 30%.

2.1.10 Arable Land

The central ecosystem of this group of habitats is agricultural land where the ground is regularly tilled and cultivated with crops (Fig. 7). Cropland, cornfields, ricefields,

Fig. 6 Saharan Desert, Tademait, Algeria

vineyards, orchards, olive groves and fallow land a short time after cultivation with typical weeds and a ruderalized herb layer are included.

Cork oak or olive plantations with a forest or woodland habit are normally excluded. This depends on the structure and species composition of the herb or shrub layer. Also grassy pastures with small groups of woody plants or single trees (crown cover <10%) are excluded and included in the grassland ecosystems.

2.1.11 Urban, Artificial and Horticultural Habitats

Cities and settlements of humans are composed by buildings, roads, ruderalized roadsides, industrial areas, railway stations and railways, parks and gardens, ruderal ecosystems beside walls, waste places, high concentrations of moving cars, people, dogs, cats, and underground constructions that have their own species compositions. The diversity of ecological conditions and thus, species diversity of certain groups of organisms is often much higher in cities than in any other group of ecosystems or rural areas in the surrounding.

2.2 Databases and Statistics

We used five databases to assess the relationship between biogeography, habitat type, threats and threatened species (Table 1): *IUCN Red List of Threatened Species* (version 2018, 2019a, b, c), *European Red List of Habitats* (Janssen et al. 2016),

Fig. 7 Rye farming in Portugal, Serra da Estrela, with *Chrysanthemum segetum* (yellow), and the generally declining and regionally extinct weed *Agrostemma githago* (red)

Plant Endemism Assessment of Red List Habitats in Europe (PEARL), *Endemic Vascular Plants in Europe* (EvaplantE), and a *database on hyperendemics* (Hypedata).

The first two are available on the internet, the latter are databases which are regularly updated by our working group. EvaplantE is a list of vascular plant taxa which are restricted to Europe. For example Hobohm and Bruchmann (2009) published an analysis which is related to a former version. PEARL is a list of all vascular plant taxa that are characteristic for predefined groups of Red List habitats in Europe (cf. Janssen et al. 2016) and the relating fact sheets. The main work on this list was on taxonomy. *Taxon-habitat relations* are defined by the combination of a taxon with a habitat type. The fifth database is a global list on hyperendemics (appendix represents an extraction). To get information on hyperendemics, we analyzed the IUCN Red List (2019a, b, c). Furthermore, we began to communicate with ecologists of certain biogeographical regions and/or taxonomic groups, and tried to implement a pyramid scheme. The personal communication began unsystematically, later on we will try to find a more systematic scheme.

The results of the analyses of all five databases indicate the meaning of predefined groups of habitats for the existence and survival of endemic and threatened species (Table 2).

Threats and numbers of endemics or threatened species of vascular plants and vertebrates are presented for the following groups of habitat types: *marine intertidal/coastal/saline, freshwater, bogs/mires/swamps, grassland, scrub/heathland, forest/woodland, sparsely vegetated rocks/screes/desert, arable,* and *urban/horticultural land.*

Table 2 General information on databases used

Database	General information	Information used
IUCN Red List on threatened species (IUCN 2018, 2019a, b, c)	Threatened taxa worldwide, online available	Critically endangered (CN), endangered (EN) and vulnerable (VU) mammal, bird, reptile, amphibian, and vascular plant species
Red List of European habitats (cf. Janssen et al. 2016)	Threatened habitats in Europe, including information about characteristic species and subspecies, online available	Information of fact sheets about occurrence of characteristic vascular plant species and subspecies, revision of taxonomies and synonymies, own analyses on endemism of all revised taxa with respect to endemism
EvaplantE	Vascular plant taxa, i.e. species and subspecies, that are endemic to Europe (apomictic microspecies are grouped)	Relationship between taxon and habitat group (habitat affinity), additional information on biogeography and ecology
PEARL	Endemic and non-endemic vascular plant taxa which are characteristic to threatened habitat types in Europe (all basic data from Janssen et al. 2016) and relating fact sheets)	Relationship between taxon and Red List habitat group (habitat affinity)
Hypedata (for an extraction cf. appendix)	Hyperendemic species and subspecies, worldwide	Taxonomy, geographic distribution

The numbers enable a comparison of the meaning of habitat types and threats for the existence and survival of endemic and threatened species in different continental regions of the world, for example in the Americas, Africa, Europe, W and Central Asia, SE Asia and Australia.

We used univariate and bivariate statistics for analyses (Zuur et al. 2007).

3 Threatened and Endemic Species

3.1 Distribution Patterns and Habitat Affinity

Table 3 represents numbers of the IUCN Red List (IUCN 2019c). They show that forests in general harbour most critically endangered species on Earth, followed by shrublands and wetlands. In forests and shrublands vascular plants harbour more critically endangered species than vertebrates, in wetlands the situation is opposite.

Wetlands harbour the second largest amount of critically endangered vertebrate species (fish species disregarded).

Table 3 Numbers of critically endangered (CR) vertebrate (amphibian, bird, reptile, mammal) and vascular plant species with respect to habitat types in different continental regions (IUCN 2019c)

Regions	Group of organisms	Forest	Shrubland	Grassland	Wetlands
World	Amphibians, birds, reptiles, mammals	1046	199	132	421
	Vascular plants (Tracheophyta)	1761	412	176	162
N America (exc. Hawaiian Islands, incl. Greenland)	Amphibians, birds, reptiles, mammals	2	1	4	4
	Vascular plants (Tracheophyta)	19	6	1	4
Mesoamerica plus Caribbean Islands	Amphibians, birds, reptiles, mammals	340	35	17	107
	Vascular plants (Tracheophyta)	160	43	6	2
S America	Amphibians, birds, reptiles, mammals	243	52	42	156
	Vascular plants (Tracheophyta)	322	53	30	12
Europe (without Russia and Greenland)	Amphibians, birds, reptiles, mammals	3	8	6	6
	Vascular plants (Tracheophyta)	81	93	19	18
Central Asia; Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	Amphibians, birds, reptiles, mammals	0	2	5	5
	Vascular plants (Tracheophyta)	1	1	0	0
S and SE Asia	Amphibians, birds, reptiles, mammals	172	25	21	46
	Vascular plants (Tracheophyta)	272	12	18	18
Sub-Saharan Africa	Amphibians, birds, reptiles, mammals	161	41	33	67
	Vascular plants (Tracheophyta)	585	90	57	82
Australia	Amphibians, birds, reptiles, mammals	30	9	7	16
	Vascular plants (Tracheophyta)	16	12	2	1

(continued)

Table 3 (continued)

Regions	Group of organisms	Rocky areas and desert	Marine neritic and intertidal	Marine coastal and supratidal	Arable land
World	Amphibians, birds, reptiles, mammals	97	46	24	34
	Vascular plants (Tracheophyta)	414	8	64	7
N America (exc. Hawaiian Islands, incl. Greenland)	Amphibians, birds, reptiles, mammals	1	3	2	2
	Vascular plants (Tracheophyta)	3	0	0	0
Mesoamerica plus Carribean Islands	Amphibians, birds, reptiles, mammals	29	15	4	5
	Vascular plants (Tracheophyta)	25	2	8	0
S America	Amphibians, birds, reptiles, mammals	16	5	0	4
	Vascular plants (Tracheophyta)	44	1	5	0
Europe (without Russia and Greenland)	Amphibians, birds, reptiles, mammals	8	3	3	4
	Vascular plants (Tracheophyta)	107	3	24	2
Central Asia; Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	Amphibians, birds, reptiles, mammals	5	1	1	4
	Vascular plants (Tracheophyta)	2	0	0	0
S and SE Asia	Amphibians, birds, reptiles, mammals	8	8	3	16
	Vascular plants (Tracheophyta)	33	2	2	0
Sub-Saharan Africa	Amphibians, birds, reptiles, mammals	15	8	7	3
	Vascular plants (Tracheophyta)	116	0	21	1
Australia	Amphibians, birds, reptiles, mammals	7	8	3	2
	Vascular plants (Tracheophyta)	4	0	1	0

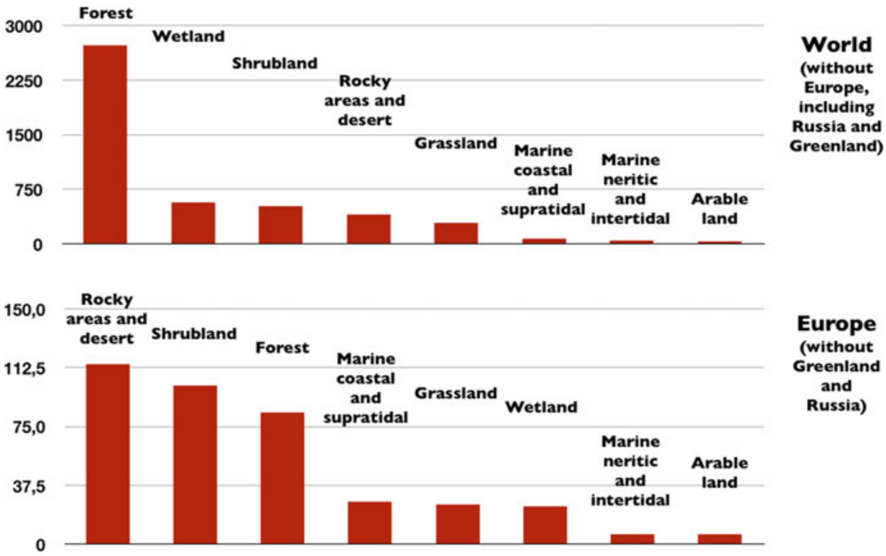

Fig. 8 Number of critically endangered (CR) vertebrate (mammal, bird, amphibian, reptile) plus vascular plant species related to habitat types in Europe and other parts of the world according to the IUCN Red List (IUCN 2019c)

Shrubland and sparsely vegetated habitat types such as rocks, screes and desert harbour the second large proportion of critically endangered vascular plant species.

Across Europe and Central Asia the situation is much different from other continental regions. Sparsely vegetated habitats such as high mountain zones, rocky places, screes, desert and semi-desert, grassland and shrubland harbour much more critically endangered and endemic species than forests (Figs. 8 and 9, Table 3).

Table 4 indicates the importance of open landscapes and forest for the life and survival of endemic vascular plants in Europe. All variables are positively correlated, many of the relationships are highly significant.

According to EvaplantE and PEARL, vasculat plant endemism in Europe is highest in rocky habitats, screes and caves. Heath and scrub, grasslands, forest, coastal and saline habitats show intermediate values whereas wetlands and artificial habitats such as arable, horticultural and urban habitats represent relatively low endemism. The European endemics in PEARL are related to Red List habitats (Janssen et al. 2016), whereas EvaplantE represents an updated list of European endemics independent of any Red List. Both variables are significantly correlated ($r = 0.89^{**}$). The number of endemics in PEARL shows a positive relationship with the number of taxon-habitat relations. However, only on the basis of these numbers a tautology can not be excluded, simply because the contributing authors of the Red List named more characteristic species if they distinguished more habitat types. However, as the high correlation-coefficient with the number in EvaplantE shows

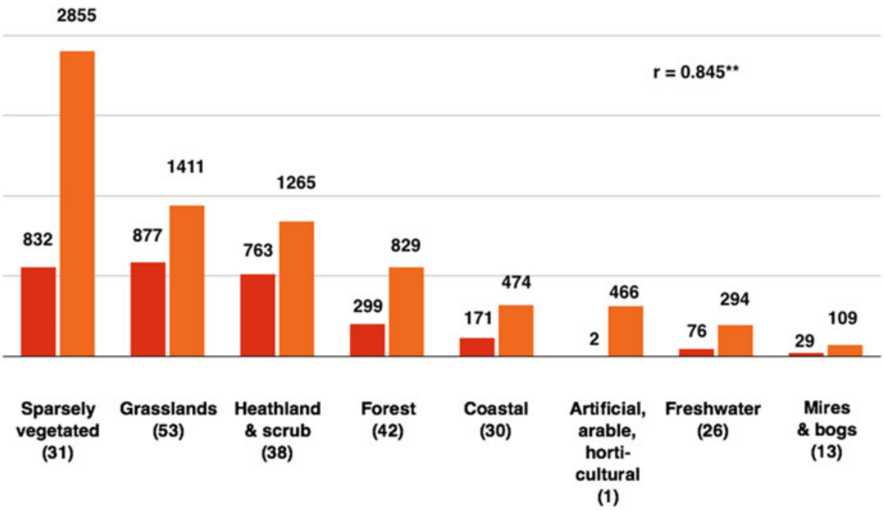

Fig. 9 Number of endemic vascular plant taxa in Red List habitats of Europe (PEARL, left) and independent of any Red List (EvaplantE, right), respectively

higher endemism in Red List habitats as predefined in Janssen et al. (2016) indeed indicates higher endemism since EvaplantE is organized independent of the number of any habitat types.

3.1.1 Distribution Patterns and Habitats of Hyperendemics

Table 5 gives an overview of the geographical distribution of hyperendemics. The numbers show that most taxa are distributed in the tropics and subtropics. Furthermore, the patterns seem to reflect the overall species richness patterns with more taxa in wet tropical and Mediterranean climate regions than in dry and cold regions.

Islands harbour 355 hyperendemics while mainland regions including Australia represent 196 hyperendemics despite a much smaller range of islands in total; islands together cover c. 7% of the terrestrial land (Sayre et al. 2019).

Also in the case of hyperendemics forest harbours the largest group of taxa. However, with respect to mainland and island regions there are obvious differences between habitat affinities. For example, coastal and marine, shrubland and rocky areas of islands harbour absolutely and relatively (percentage) more hyperendemics than mainland regions. The situation in wetland and grassland habitats seems to be opposite, with more taxa on the mainland (Table 6).

Table 4 Endemic and non-endemic vascular plant taxa in habitats of Europe (according to Janssen et al 2016, and recent versions of EvaplantE and PEARL); *taxon* in this case refers to species, subspecies or group of apomictic microspecies of vascular plants. Note that many taxa occur in more than one habitat type

	EvaplantE	PEARL			
Habitat group	No. of endemic vascular plants	No. of taxon-habitat relations	Endemics (no. of taxa which are endemic to Europe and characteristic for Red List habitats)	Non-endemics (no. of non-end. which are characteristic for Red List habitats in Europe)	Level of endemism (in habitats of the Red List of European habitats) (%)
All	6257	10,495	2797	3396	45
AB Coastal, Brackish and Saline Habitats	474	1122	171	576	23
C Freshwater Habitats	294	644	67	400	14
D Bogs, Mires and Fens	109	433	29	186	13
E Grasslands	1411	3104	877	1508	37
F Heath and scrub	1265	1854	763	732	50
G Forests	829	1579	299	547	34
H Rocky habitats, screes and caves	2855	1695	832	511	60
I Agricultural, horticultural and domestic habitats	466	53	2	47	4

3.1.2 Examples of Hyperendemics

A couple of species are represented in the nature by a last individual only. For example, no more than a single mature individual of the vascular plants *Aegiphila caymanensis, Bhesa sinica, Brighamia insignis, Carpinus putoensis, Commidendrum rotundifolium, Cyanea truncata, Dichapetalum letouzeyi, Holmskioldia gigas, Hyophorbe amaricaulis, Pennantia baylisiana, Pritchardia munroi, Ramosmania rodriguesii,* and *Sorbus parviloba* have recently been observed (IUCN 2019c; also for the following examples if no other references cited).

Table 5 Geographical distribution of hyperendemics including species, subspecies and apomictic microspecies (refs. see text)

Mainland North Americas	No. of hyperendemics	Mainland Europe	No. of hyperendemics	Mainland Africa	No. of hyperendemics	Mainland Asia and Australia	No. of hyperendemics
North America	5	Europe	46	Africa	33	Asia	55
USA	4	Austria/Czech Republic	1	Cameroon	12	Armenia	2
Canada/USA	1	Czech Republic	5	Ethiopia	1	Bhutan	1
		France	1	French Guiana	1	China	21
South America	54	Germany	16	Gabon	1	China/ Vietnam	2
Brazil	11	Greece	1	Guinea/ Liberia	1	India	7
Colombia	9	Hungary	9	Kenya	3	Kazakhstan	1
Colombia/Ecuador	1	Macedonia	1	Mali	1	Russian Federation	1
Costa Rica	4	Portugal	1	Morocco	4	Thailand	2
Ecuador	4	Slovakia	7	Nigeria	1	Turkey	4
Guatemala	1	Spain	2	Nigeria/ Came-roon	1	Vietnam	14
Mexico	15	Sweden	1	South Africa	2		
Mexico/Guatemala	1	Ukraine	1	Tanzania	5		
Panama	2						
Panama/Costa Rica	1					Australia	3
Peru	2						
Venezuela	2						
Venezuela/Colombia	1						

Islands North Atlantic, Carribean Sea, Mediterranean Sea	90	Islands South Atlantic	8	Islands Indian Ocean, Red Sea	100	Islands North Pacific	120
Azores	1	Ascension Islands	1	Andaman Islands (India)	1	Putuo Island (China)	1
Bahamas	1	Saint Helena	4	Madagascar	59	Hawaii (USA)	80
Balearic Is. (Spain)	2	Tristan da Cunha/ Ascension	1	Mauritius	30	Indonesia	14
Bermuda (UK)	1	Ascension Is., Saint Helena, Tristan da Cunha	1	Seychelles	7	Indonesia/ Malaysia	1
Canary Is. (Spain)	15	Moleques do Sul (Brazil)	1	Sri Lanka	2	Japan	4
Cape Verde	7			Socotra (Yemen)	1	Malaysia	8
Cayman Islands	3					Micronesia	1
Corsica (France)	1					Palau	3
Cozumel Island (Mexico)	1					Philippines	6
Cuba	1					Taiwan	2
Dia Island (Greece)	1						
Haiti	2					Islands South Pacific	37
Ireland	1					Cook Islands	6
Jamaica	2					Fiji	7
Madeira (Portugal)	14					French Polynesia (France)	3

(continued)

Table 5 (continued)

Mainland North Americas	No. of hyperendemics	Mainland Europe	No. of hyperendemics	Mainland Africa	No. of hyperendemics	Mainland Asia and Australia	No. of hyperendemics
Puerto Rico (USA)	9					Galápagos (Ecuador)	3
Saint Lucia	1					New Caledonia (France)	10
Sardinia (Italy)	2					New Zealand	4
Sicily (Italy)	5					Papua New Guinea	1
United Kingdom	19					Tasmania (Australia)	2
United Kingdom/Ireland	1					Vanuatu	1

Table 6 Selected habitat groups of hyperendemics. Every hyperendemic taxon can occur in more than a single habitat group. Furthermore, only 492 taxa are characterized by habitat affinity. Thus, the sum of percentage values exceeds 100% in total (cf. IUCN 2019c)

Habitat group	Mainland (174)	Islands (318)
Forest	136 (69%)	240 (68%)
Shrubland	20 (10%)	64 (18%)
Grassland	18 (9%)	10 (3%)
Wetlands (inland)	22 (11%)	17 (5%)
Rocky areas	25 (13%)	61 (17%)
Marine intertidal	0	2 (1%)
Marine coastal/supratidal	0	13 (4%)
Artificial/terrestrial	4 (2%)	9 (3%)

One single juvenile and a freshly dead adult of the mollusc *Partula emersoni* was recorded on Pohnpei Island, Micronesia, in 2011.

Many observations and records are already a couple of years if not two decades old, and it is questionable if all these species still exist. On the other hand, especially vascular plant species such as *Euphorbia margalidiana* or *Wollemia nobilis* are cultivated in certain botanical gardens and are an object of related breeding programmes. Today it is possible to buy *Wollemia* via internet. Thus, it can be assumed that the survival of these species at least in horticulture is guaranteed.

Choleva septentrionis subsp. *holsatica* is an insect living in a cave in Bad Segeberg, Germany. Because of the geology and history of this cave and because of genetic analysis it must be assumed that this insect is an evolutionary relatively young taxon (Heun 1955; Ipsen and Tolasch 1997; Ruzicka and Vavra 2003). The same can be assumed for plant species of genera with many apomict species such as *Alchemilla, Taraxacum, Sorbus, Rubus, Hieracium* and others in Europe.

Wollemia nobilis is representing the opposite, a putative old and monotypic taxon or living fossil which was discovered in Australia in 1994 (Jones et al. 1995; Chambers et al. 1998; Woodford 2000).

The plant family of the Euphorbiaceae is relatively old and hybridization between species is rarely observed, with the exception of succulent Euphorbias on Canary Islands (Borgen 1979; Izquierdo et al. 2004; Molero and Rovira 2005). However, *Euphorbia margalidiana*, synonymous to *Euphorbia squamigera* subsp. *margalidiana* is not very different from *Euphorbia squamigera* subsp. *squamigera* which is also native to the Balearic Islands. Thus, the hyperendemic on Ses Margalides might have been evolved via genetic drift, and it can be assumed that this taxon is of intermediate age (Castroviejo et al. 1997).

3.2 Threats

With respect to predefined threat categories of the IUCN (2019c), agriculture and aquaculture including tree plantations and nomadic grazing, and biological resource use including illegal hunting and collection of roots, fruits, herbs, etc. are the most important threats to endangered species of the IUCN Red List (Table 7, Fig. 10).

Table 7 Number of critically endangered species with respect to threat categories and continental region (cf. IUCN 2019c)

Land regions	Group of organisms	Residential and commercial development, transportation	Agriculture and aquaculture including wood plantations and nomadic grazing	Biological resource use	Invasive species	Pollution	Climate change and severe weather
World	Amphibians, birds, reptiles, mammals	436	945	847	592	226	279
	Vascular plants (Tracheophyta)	563	1429	1145	667	100	386
N America (exc. Hawaiian Islands, incl. Greenland)	Amphibians, birds, reptiles, mammals	2	4	8	5	2	3
	Vascular plants (Tracheophyta)	9	8	7	22	2	8
Mesoamerica plus Carribean Islands	Amphibians, birds, reptiles, mammals	173	288	264	208	53	82
	Vascular plants (Tracheophyta)	90	154	137	25	2	52
S America	Amphibians, birds, reptiles, mammals	84	243	158	149	80	54
	Vascular plants (Tracheophyta)	75	189	123	37	8	13
Europe (without Russia and Greenland)	Amphibians, birds, reptiles, mammals	3	10	14	7	5	5
	Vascular plants (Tracheophyta)	41	90	45	103	21	39

Central Asia; Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan	Amphibians, birds, reptiles, mammals	2	10	7	3	4	3
	Vascular plants (Tracheophyta)	3	10	9	0	0	1
S and SE Asia	Amphibians, birds, reptiles, mammals	76	152	168	35	45	41
	Vascular plants (Tracheophyta)	141	213	234	16	16	29
Sub-Saharan Africa	Amphibians, birds, reptiles, mammals	54	174	158	65	27	39
	Vascular plants (Tracheophyta)	102	545	471	144	26	48
Australia	Amphibians, birds, reptiles, mammals	17	22	22	40	14	26
	Vascular plants (Tracheophyta)	7	11	0	13	2	4

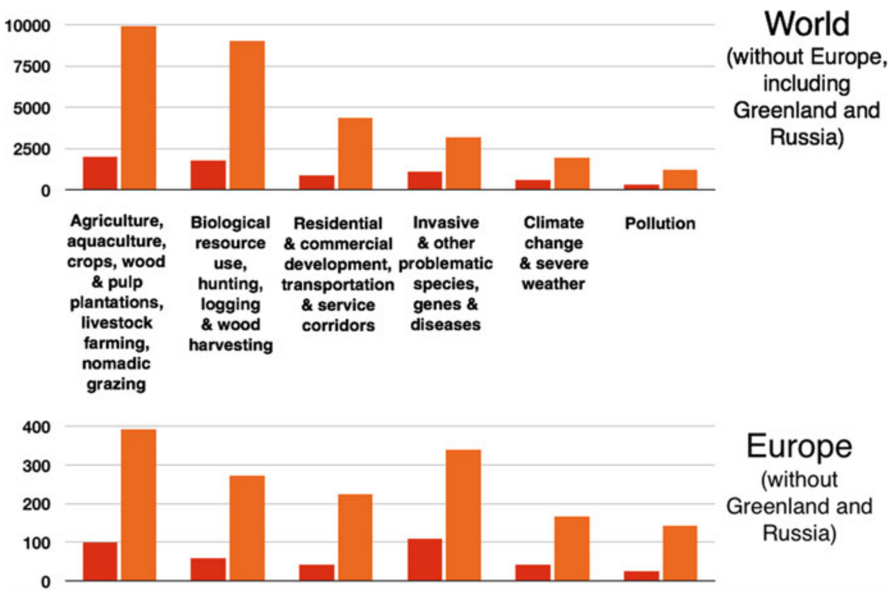

Fig. 10 No of critically endangered (CR; left) and threatened (CR, EN, VU; right) species. The figure shows that agriculture, aquaculture, biological resource use, i.e. crop, wood and pulp production, livestock farming and nomadic grazing at global scales and also across Europe are the most important factors threatening the species diversity

Residential and commercial development, together with transportation and service corridors and dams and water management modifications cause the third important bundle of threats.

Invasive and other problematic species, genes and diseases take position four. Climate change and severe weather is the fifth important threat category, and pollution is taking number six.

Except for Australia where climate change and severe weather is assessed as third important threat category after invasive and other problematic species and agriculture this factor in most other regions is taking position number four or five (cf. Table 7).

Figures 11 and 12 indicate the increasing effect of invasive and other problematic species, genes and diseases with increasing pressure and/or decreasing range of the threatened species. We assume that the increasing effect of invasive species might depend on isolation effects. For example, snakes introduced on a small island can cause a dramatic decline of ground-breeding birds if such predator has not been there before. This was the case on Guam where the Brown Treesnake, *Boiga irregularis*, in the 1950s was introduced and depleted the avifauna (Rodda et al. 1992; Burnett et al. 2006).

For hyperendemics the most important threat category is invasive and other problematic species, genes and diseases. The pressure caused by agriculture and aquaculture, and biological resource use is high as well.

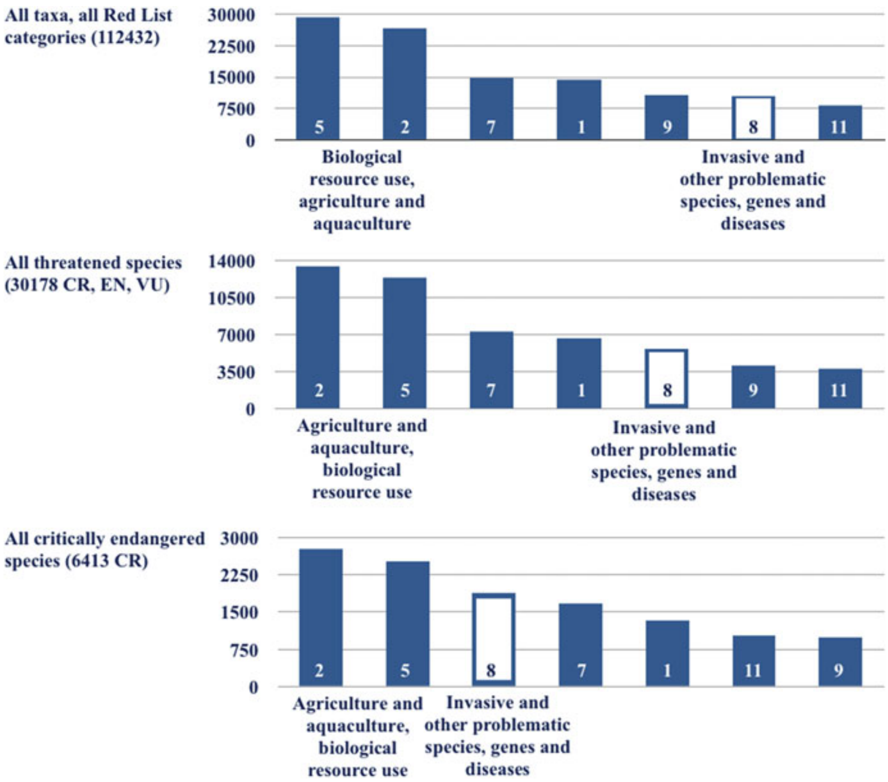

Fig. 11 Threats caused by invasive and other problematic species, genes and diseases for all taxa, for threatened, and critically endangered species of the IUCN Red List (IUCN 2019c); numbers refer to threat categories, e.g. 1: Residential and commercial development, 7: Natural system modifications, 9: Pollution, 11: Climate change and severe weather (other numbers explained in fig.)

However, in the case of hyperendemics it is possible to distinguish between species living in mainland regions and on islands (Table 8). In general, invasive and other problematic species, geological events and severe weather are assessed as more problematic for hyperendemics on islands than in mainland regions. In contrary, pollution has a stronger impact in mainland regions than on islands.

4 Discussion and Outlook

The databases used here, represent information on a huge amount of endemic and threatened species and relating geographical, evolutionary, taxonomic, ecological and environmental characteristics and classifications. For all of them a large number

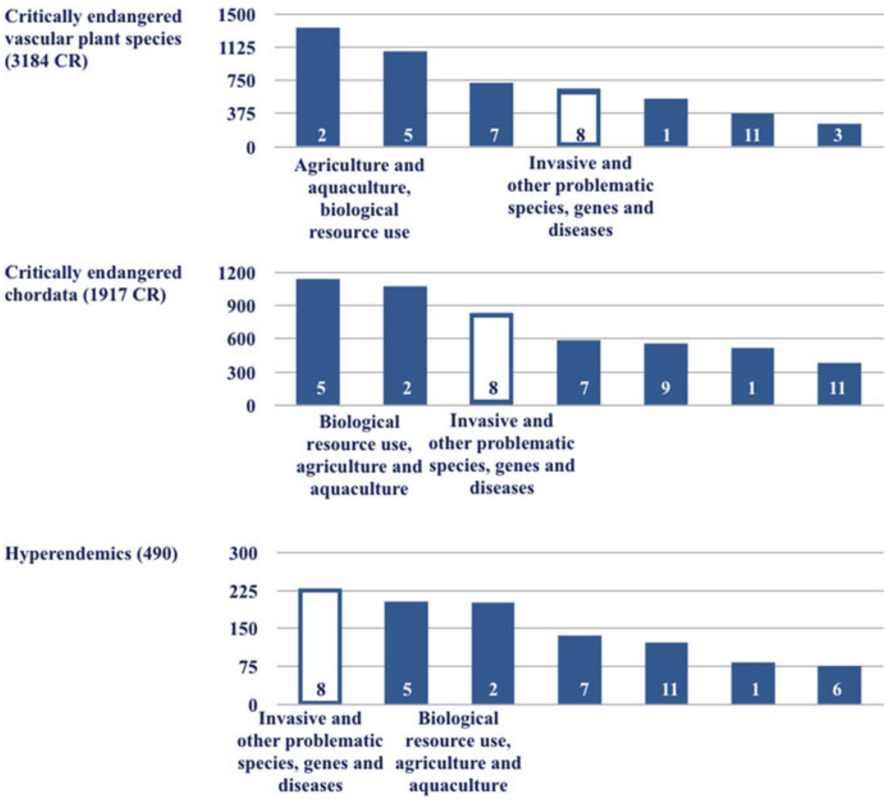

Fig. 12 Threats caused by invasive and other problematic species, genes and diseases for critically endangered vascular plant, chordata and hyperendemic species of the IUCN Red List (IUCN 2019c); numbers refer to threat categories, e.g. 1: Residential and commercial development, 3: Energy production and mining, 6: Human intrusions and disturbance, 7: Natural system modifications, 9: Pollution, 11: Climate change and severe weather

of scientists collected data during long times. However, expert groups represent scientific communities of different size. They not in every case use scientific terms or a species concept in the same meaning. Thus, the expert knowledge and resulting information on different taxa, habitat types, and regions on Earth is not equally distributed (e.g. Cardoso et al. 2020). Moreover, there are indications that e.g. the IUCN Red List and the list of hyperendemics presented here are biased with respect to taxonomy and geography. Most species of these lists belong to vascular plants and vertebrates. Since much more species on Earth are invertebrates (insects, molluscs etc.), and because many of them also have small ranges (e.g. Wang et al. 2017; Wynne 2017) it can be assumed that invertebrates are underrepresented.

Almost 10% of the list of hyperendemics (54 species) belong to *Sorbus* (53) and *Rubus* (1), Rosaceae. *Sorbus* is a genus with a majority of apomictic microspecies. All *Sorbus* and the one *Rubus* species listed here were described for European

Table 8 Main threat categories to hyperendemics on mainland and islands (N = 490). Every hyperendemic taxon can be threatened by more than one factor. Furthermore, not all taxa are characterized by threat category. Thus, the sum of percentage values exceeds 100% (cf. IUCN 2019c)

Threat categories	Mainland (158)	Islands (332)
Residential and commercial development (82)	32 (16%)	50 (14%)
Agriculture and aquaculture (200)	74 (38%)	126 (35%)
Biological resource use (202)	78 (40%)	124 (35%)
Natural system modifications (135)	54 (28%)	81 (23%)
Invasive and other problematic species, genes and diseases (229)	35 (18%)	194 (55%)
Pollution (29)	22 (11%)	7 (2%)
Geological events (39)	1 (1%)	38 (11%)
Climate change and severe weather (121)	23 (12%)	98 (28%)

countries. Furthermore, compared to other European countries Germany and UK represent relatively high numbers.

If all apomictic taxa would be listed with the same intensity and awareness for all countries, most likely the numbers and relations would strongly increase. In general, it is questionable if apomictic taxa, microspecies or subspecies should be listed or excluded from such lists. However, for the first version of Hypedata we took all available information and did not exclude any taxon.

All databases and contributions with information about biodiversity have to be updated regularly. And even if the knowledge is rapidly growing such a database can never be perfect or complete. Nevertheless, we are convinced that it is meaningful to use such lists with required prudence. However, because of supposed biases we did not quantify all relationships.

Moreover, we already started to communicate with many scientists in the world to get more information especially on invertebrates wherever we assumed to get information which has not or only regionally been published. The personal communication already shows that we can expect much more local and hyperendemics for example in Coleoptera (e.g. Carabidae) and molluscs (many gastropods) as well as in amphibians where microendemic species e.g. of Micorhylids and *Atelopus* spp. are widespread. In case of terrestrial snails, the number of species significantly increased after communication with malacologists from islands and archipelagos. Due to the first results of focussing on certain areas like habitat islands such as caves and sources we can expect an increasing number of hyperendemic species also on the mainland.

We also conclude that the restriction of a taxon to a single square kilometer or a population of 50 individuals or less for many taxa like most groups of flying insects is not an adequate category. Thus, depending on the taxonomic group a systematic reflecting a *large*, *normal* or *small* range and a critical population size for all taxonomic groups should be developed.

Acknowledgements We would like to gratefully acknowledge Biljana Budzakoska Gjoreska, Hydrobiological Institute Ohrid, Macedonia, Milan Chytry, Masaryk University, Brno, Czech Republic, Gregor Degasperi, Austria, Klaus Groh, Project Team Molluscs-Mapping, Bad Dürckheim, Germany, Manfred Kahlen, Tyrolean State Museums, Ferdinandeum, Austria, Christian Komposch, University of Graz and Klagenfurt, Austria, Petr Maděra, Mendel University, Brno, Czech Republic, Wolfgang Paill, Natural History Museum, Austria, Samuel G. Penny, University of Brighton, UK, Gonçalo M. Rosa, Zoological Society of London, UK, Ulf Ryde, Lund University, Sweden, Soumid Fahd, Abdelmalek Essaâdi University, Tétouan, Morocco, Dinarte Teixeira, Institute of Forests and Nature Conservation IP-RAM, Madeira, Portugal, Sula Vanderplank, Institute for Conservation Research, San Diego, United States, Raquel Vasconcelos, University of Porto, Portugal and Jut Wynne, Northern Arizona University, United States, and thank for information on several local endemics and hyperendemics.

Appendix

List of hyperendemics in alphabetical order with information on systematics and geography/microhotspots (Heun 1955; Kuhbier 1978; Schilthuizen 1990; Ipsen and Tolasch 1997; de Montmollin and Strahm 2005; Lorenzi et al. 2010; Baillie and Butcher 2012; IUCN Red List 2018, 2019a, b, c). The list represents an extraction of the database on hyperendemics (Hypedata).

Abies beshanzuensis, Pinaceae, China, Zhejiang Baishanzu Mountains, *Abies nebrodensis*, Pinaceae, Italy, Sicily, Madonie Mountains, *Abronia frosti*, Anguidae, Guatemala, los Cuchumatanes, *Acanthothecis leucoxanthoides*, Ascomycota, Graphidaceae, USA, North Carolina, SE Coastal Plain, *Acanthothecis paucispora*, Ascomycota, Graphidaceae, USA, North Carolina, *Aegiphila caymanensis*, Verbenaceae, Cayman Islands, Grand Cayman, *Aichryson dumosum*, Crassulaceae, Portugal, Madeira, *Allobates juanii*, Aromobatidae, Colombia, Villavicencio, *Aloe helenae*, Aloaceae, Madagascar, Fort Dauphin, *Alsinidendron obovatum*, Caryophyllaceae, Hawaii, O'ahu, Waianae Mountains of O'ahu, *Anogramma ascensionis*, Pteridiaceae, Ascension Island, Green Mountain area, *Artemisia insipida*, Asteraceae, France, Haute-Alpes region, *Asplenium dielerectum*, Aspleniaceae, Hawaii, *Asplenium schizotrichum*, Aspleniaceae, Cook Islands, Rarotonga, *Astelia waialealae*, Asteliaceae, Hawaii, Kaua‘i, Alaka‘i Swamp area, *Atelopus nocturnus,* Bufonidae, Colombia, Cordillera Central municipality of Anorí, Antioquia Department, *Attalea crassispatha,* Arecaceae, Haiti, *Auerodendron pauciflorum*, Rhamnaceae, Puerto Rico, *Aythya innotata*, Anatidae, Madagascar, *Bactris nancibensis*, Arecaceae, French Guiana, Cayenne region, *Badula platyphylla,* Myrsinaceae, Mauritius, *Begonia salaziensis*, Begoniaceae, Mauritius, Bel Ombre, *Bencomia sphaerocarpa*, Rosaceae, Spain, Canary Islands, El Hierro, *Berlinia hollandii*, Fabaceae, Nigeria, Calabar, *Berlinia korupensis*, Fabaceae, Cameroon, Korup National Park, *Betula chichibuensis*, Betulaceae, Japan, Chichibu area, mountains of Central Honshu on Mt. Kamo-san, *Betula klokovii*, Betulaceae, Ukraine, Ternopil region, *Betula murrayana*, Betulaceae, USA, Michigan, and Ontario, Canada, *Bhesa sinica*, Celastraceae, China, Guangxi, near Nankan, *Bonnetia ptariensis*, Bonnetiaceae, Venezuela, Canaima National Park, *Brighamia insignis*, Campanulaceae, Hawaii, Kaua'i, *Buchanania barberi*, Anacardiaceae, India, Kerala, Palode region, *Calophyllum africanum*, Calophyllaceae, Mali, border to Guinea Falea, *Camellia bugiamapensis*, Theaceae, Vietnam, Cambodian border to the Bu Gia Map National Park Binh Phuoc Province, *Camellia capitata,* Theaceae, Vietnam, Dong Province Cat Tien National Park, *Camellia crassiphylla*, Theaceae, Vietnam, Tam Dao National Park, *Camellia cucphuongensis*, Theaceae, Vietnam, Cuc Phuong National Park, *Camellia duyana*, Theaceae, Vietnam, Lam Dong Provinice, *Camellia oconoriana*, Theaceae, Vietnam, S Lam Dong Province, *Camellia piquetiana*, Theaceae, Vietnam, S, near Da Lat City, *Camellia rubriflora*, Theaceae, Vietnam, Tam Dao National Park, *Carex antoniensis*, Cyperaceae, Cape Verde, Santo Antão Island, Ribeira Paul, *Carex collifera,* Cyperaceae, Japan, Okinawa Island in Ryukyu Islands, *Carpinus langaoensis*, Betulaceae, China, Daba Mountains in the Shanxi, *Carpinus putoensis*, Betulaceae, China, Putuo Island of the Zhoushan Archipelago Zhejiang Province, *Carpinus tientaiensis*, Betulaceae, China, NW Province of Zhejiang Tiantai Mountain, *Carpoxylon macrospermum*, Arecaceae, Vanuatu, Aneityum Tanna and Futuna, *Casearia staffordiae*, Salicaceae, Cayman Islands, Grand Cayman, Mastic Forest region, *Cassipourea korupensi*, Rhizophoraceae, Cameroon, Korup National Park, *Cavia intermedia*, Caviidae, Brazil, Moleques Island do Sul Archipelago, State of Santa Catarina, *Centranthus amazonum*, Valerianaceae, Italy, Sardinia, Mount Oliena, *Ceratocentron fesselii*, Orchidaceae, Philippines, Luzon Island Nueva Ecija, *Chenopodium flabellifolium*, Amaranthaceae, Mexico, Baja California, *Choleva septentrionis subsp. holsatica*, Leiodidae, Germany, Bad Segeberg, *Cinnamomum chemungianum*, Lauraceae, India, Kerala, Thiruvananthapuram, Chemungi Hills, *Cipocereus pusilliflorus*, Cactaceae, Brazil, Minas Gerais Serra Geral, central-N, *Cirsium davisianum*, Asteraceae, Turkey, Anatolia, Erzurun regeion, *Cirsium eliasianum*, Asteraceae, Turkey, Anatolia, Erzurun region, *Claoxylon linostachys*, Euphorbiaceae, Mauritius, Petrin, *Clermontia peleana*, Campanulaceae, Hawaii, Hawai'i, *Clermontia pyrularia*, Campanulaceae, Hawaii, Hawai'i, Mauna Kea, *Coleochloa domensis*, Cyperaceae, Cameroon, NW region, Dom community, *Columba argentina*, Columbidae, Borneo, Indonesia and Malaysia, and Sumatra, *Commidendrum rotundifolium,* Asteraceae, Saint Helena, SW coastal hills, *Commidendrum spurium*, Asteraceae, Saint Helena, W Central Ridge, *Connarus ecuadorensis*, Connaraceae, Ecuador, El Oro province, close to Rio Dumari, *Consolea falcata*, Cactaceae, Haiti, Saint Michelle, W side, *Conyza schlechtendalii*, Asteraceae, Cape Verde, São Nicolau Island, Archipelago Alto das Caba, Alto das Cabaças archipelago, *Coprosma laevigata*, Rubiaceae, Cook Islands, Rarotonga, *Costus barbatus*, Costaceae, Costa Rica, San Jose, *Costus vinosus*, Costaceae, Panama, Sierra Llorona, Santa Rita Ridge, *Cotoneaster cambricus*, Rosaceae, UK, Great Britain, Wales, Great Orme's Head, Caernarvonshire Llandudno, *Cotoneaster majoricensis*, Rosaceae, Spain, Balearic Islands Mallorca, N mountains, *Crambe wildpretii*, Brassicaceae, Spain, Canary Islands, La Gomera, NW of the island, *Crataegus turcicus,* Rosaceae, Turkey, Anatolia, NE Artvin, *Craugastor fleischmanni*, Craugastoridae, Costa Rica, Rio Ciruelas, *Crax pinima*, Cracidae, Brazil, NE Amazonia, Maranhão Gurupi, Biological Reserve, *Cyanea asarifolia*, Campanulaceae, Hawaii, Kaua'i, *Cyanea crispa*, Campanulaceae, Hawaii, O'ahu, Koolau Mts., *Cyanea dunbariae*, Campanulaceae, Hawaii, Moloka'i, *Cyanea gibsonii*, Campanulaceae, Hawaii, Lana'i, *Cyanea glabra*, Campanulaceae, Hawaii, Maui, *Cyanea grimesiana*, Campanulaceae, Hawaii, O'ahu, Wai'anae Mountains, *Cyanea horrida*, Campanulaceae, Hawaii, Maui, *Cyanea humboldtiana*, Campanulaceae, Hawaii, O'ahu, Ko'olau Mt. Range, *Cyanea kuhihewa*, Campanulaceae, Hawaii, Kaua'i, Limahuli Valley, *Cyanea lobata subsp. baldwinii*, Campanulaceae, Hawaii, Lāna'i, Maui, *Cyanea magnicalyx*, Campanulaceae, Hawaii, Maui, *Cyanea marksii*, Campanulaceae, Hawaii, Hawai'i, Kona district, *Cyanea platyphylla*, Campanulaceae, Hawaii, Hawai'i, S Kona, *Cyanea remyi*, Campanulaceae, Hawaii, Kaua'i, *Cyanea rivularis*, Campanulaceae, Hawaii, Kaua'i, *Cyanea shipmanii*, Campanulaceae, Hawaii, Kaua'i, *Cyanea st-johnii*, Campanulaceae, Hawaii, O'ahu, *Cyanea truncata*, Campanulaceae, Hawaii, O'ahu, *Cyanea undulata*, Campanulaceae, Hawaii, Kaua'i, *Cyanopsitta spixii*, Psittacidae, Brazil, N Bahia, *Cylindrocline commersonii*, Asteraceae, Mauritius, Montagne, Le Pouce, *Cyphosperma naboutinense*, Arecaceae, Fiji, Serua, Province on Viti Levu Naboutini, *Cypripedium froschii*, Orchidaceae, China, Yunnan (Lijiang), *Cypripedium taibaiense*, Orchidaceae, China, Shaanxi, Taibai Muntain, *Cyrtandra kaulantha*, Gesneriaceae, Hawaii, O'ahu, Koolau Mountains, *Cyrtandra paliku*, Gesneriaceae, Hawaii, Kaua'I, Koolau Mountains, Makaleha Range, *Cyrtandra rarotongensis*, Gesneriaceae, Cook Islands, Rarotonga, *Delissea rhytidosperma*, Campanulaceae, Hawaii, Kaua'i, *Delosperma macellum*, Aizoaceae, South Africa, Gauteng near Heidelberg and Vereeniging, *Dendrobium schuetzei*, Orchidaceae, Philippines, Mindanao Islands, *Dichapetalum korupinum,* Dichapetalaceae, Cameroon, SW Region of Korup National Park, *Dichapetalum letouzeyi*, Dichapetalaceae, Cameroon, SW Region of Korup National Park, *Dimorphandra wilsonii*, Fabaceae, Brazil, SE Minas Gerais State: Paraopeba and Caetanópolis municipalities, *Dioscorea decaryana*, Dioscoreaceae, Madagascar, Ambatofinandrahana area, *Diospyros veillonii*, Ebenaceae, New Caledonia, Paita Region, *Diplotaxis glauca*, Brassicaceae, Cape Verde, Islands Sal and Boavista, *Dipterocarpus cinereus*, Dipterocarpaceae, Indonesia, Sumatra, Mursala Island, *Dipterocarpus littoralis*, Dipterocarpaceae, Indonesia, Java, Nusakambangan Island, *Ditrichum cornubicum*, Ditrichaceae, Ireland, UK, Great Britain, England, Cornwall, and Ireland, Co. Cork, *Diuris byronensis*, Orchidaceae, Australia, New South Wales Bryon Bay, *Dovyalis cameroonensis,* Salicaceae, Nigeria, SE, Obudu Cattel Ranch and Cameroon, Bameda Highlands, *Dracaena tamaranae,* Asparagaceae, Spain, Canary Islands, Gran Canaria, SW sector, *Dryococelus australis*, Phasmatidae, Australia, Lord Howe Island Balls Pyramid, *Drypetes riseleyi,* Putranjivaceae, Seychelles, Mahé, Praslin Silhouette, *Dubautia kalalauensis*, Asteraceae, Hawaii, Kaua'i, Kalalau Valley, *Dudleya crassifolia*, Crassulaceae, Mexico, Baja California, *Dudleya hendrixii*, Crassulaceae, Mexico, Baja California, *Dudleya pachyphytum*, Crassulaceae, Mexico, Baja California, *Duvaliandra dioscoridis*, Apocynaceae, Yemen, Socotra, central mountains, *Dypsis albofarinosa,* Arecaceae, Madagascar, W of Andringitra area, *Dypsis ambanjae*, Arecaceae, Madagascar, between Tsaratanana Mts. & Daraina, *Dypsis ambositrae*, Arecaceae, Madagascar, Ambositra central Haut Plateau, *Dypsis ampasindavae*, Arecaceae, Madagascar, Sambirano region, *Dypsis andilamenensis*, Arecaceae, Madagascar, Andilamena, *Dypsis antanambensis*, Arecaceae, Madagascar, Mananara Avaratra, *Dypsis basilonga*, Arecaceae, Madagascar, Mont Vatovavy & Andrambovato Mt., *Dypsis beentjei*, Arecaceae, Madagascar, Mananara Avaratra, *Dypsis brevicaulis,* Arecaceae, Madagascar, Tolagnaro region, *Dypsis brittiana,* Arecaceae, Madagascar, Tsaramain'Andro vicinity, *Dypsis canaliculata,* Arecaceae, Madagascar, Zahamena National Park, *Dypsis carlsmithii*, Arecaceae, Madagascar, Tampolo & Mahavelona, *Dypsis caudata,* Arecaceae, Madagascar, Antalavia Masoala National Park, *Dypsis cookei,* Arecaceae, Madagascar, Marojejy National Park, *Dypsis elegans*, Arecaceae, Madagascar, between Mahanoro & Taolagnaro, *Dypsis gronophyllum*, Arecaceae, Madagascar, Vondrozo forest, *Dypsis humilis*, Arecaceae, Madagascar, WNW of Maroantsetra, *Dypsis ifanadianae*, Arecaceae, Madagascar, area near Ifanadiana, *Dypsis intermedia*, Arecaceae, Madagascar, Farafangana, Manombo Reserve, *Dypsis interrupta*, Arecaceae, Madagascar, Ifanadiana and Manombo Reserve, *Dypsis jeremiei*, Arecaceae, Madagascar, Soanierana, Ivongo, Ambatovaky Reserve, *Dypsis laevis*, Arecaceae, Madagascar, Farafangana, Manombo Reserve, *Dypsis lanuginosa*, Arecaceae, Madagascar, Ambatovaky, *Dypsis leptocheilos*, Arecaceae, Madagascar, Maevatanana, *Dypsis mangorensis*, Arecaceae, Madagascar, Mananara Avaratra National Park, *Dypsis nauseosa*, Arecaceae, Madagascar, Manakara, Mananjary, Farafangana, Vondrozo, *Dypsis nossibensis*, Arecaceae, Madagascar, Nosy Be Island, Lokobe forest, *Dypsis oropedionis*, Arecaceae, Madagascar, central plateau Ankazobe and Tsiroanomandidy, *Dypsis ovobontsira*, Arecaceae, Madagascar, Mananara Avaratra National Park, *Dypsis pervillei*, Arecaceae, Madagascar, Soanierana Ivongo, *Dypsis pulchella,* Arecaceae, Madagascar, Andilamena, *Dypsis pumila,* Arecaceae, Madagascar, Marojejy Mountains, *Dypsis ramentacea,* Arecaceae, Madagascar, Mananara, *Dypsis remotiflora,* Arecaceae, Madagascar, Mangerivola, *Dypsis robusta,* Arecaceae, Madagascar, Ifanadiana, *Dypsis sahanofensis,* Arecaceae, Madagascar, Mont Vatovavy, *Dypsis scandens,* Arecaceae, Madagascar, Ifanadiana area, *Dypsis tanalensis,* Arecaceae, Madagascar, Vondrozo, *Dypsis tokoravina,* Arecaceae, Madagascar, Mananara Avaratra Masoala, Peninsula Mahavelona, *Dypsis trapezoidea,* Arecaceae, Madagascar, Mont Vatovavy, *Dypsis vonitrandambo,* Arecaceae, Madagascar, Masoala National Park, *Eligmocarpus cynometroides,* Fabaceae, Madagascar, SW of Taolañaro Petriky, *Encephalartos sclavoi,* Zamiaceae, Tanzania, Tanga distirict, Usambara mountains, *Encyclia kingsii,* Orchidaceae, Cayman Islands, *Ensete perrieri,* Musaceae, Madagascar, Analavelona, Ampefy, Bemaraha, Maintirano, *Epipactis hyblaea,* Orchidaceae, Italy, Sicily, Valle dell'Anapo e Torrente Cava Grande, *Eremospatha barendii,* Arecaceae, Cameroon, along Melange River and Ebom, *Erythrina schliebenii,* Fabaceae, Tanzania, Kilwa Namatimbili Forest, *Erythrolamprus ornatus,* Dipsadidae, Saint Lucia, offshore island Maria Major, *Eugenia crassipetala,* Myrtaceae, Mauritius, Lion mountain Case, Noyale and Montagne Le Chat, *Euphorbia anachoreta,* Euphorbiaceae, Portugal, Madeira (Selvagens Islands), *Euphorbia* *margalidiana,* Euphorbiaceae, Spain, Balearic Islands, Ses Margalides, *Euphorbia piceoides,* Euphorbiaceae, Ethiopia, Hararge region, *Euphorbia tanaensis,* Euphorbiaceae, Kenya, Witu Forest reserve, *Eurya zigzag,* Pentaphylacaceae, Japan, Okinawa Island in Ryukyu Islands, *Eutrichomyias rowleyi,* Monarchidae, Indonesia, Sangihe Island, *Ficus lateriflora,* Moraceae, Mauritius, Réunion, *Fissidens azoricus,* Fissidentaceae, Portugal, Azores, Island of Flores, *Fissidens jansenii,* Fissidentaceae, Portugal, Serra da Estrela, *Flueggea neowawraea,* Phyllanthaceae, Hawaii, Kauai, Oahu, Molokai, Maui and Kona coast on Hawai'i, *Fregetta maoriana,* Oceanitidae, New Zealand, Mercury Islands, Hauraki gulf, N of Little Barrier Island, *Gaertnera hirtiflora,* Rubiaceae, Mauritius, Maccabe forest, *Gaertnera truncata,* Rubiaceae, Mauritius, *Gallotia bravoana,* Lacertidae, Spain, Canary Islands, La Gomera, Valle Gran Rey, *Gardenia anapetes,* Rubiaceae, Fiji, Vanua Levu, Mt. Kasi, Mt. Seatura, *Gardenia brighamii,* Rubiaceae, Hawaii, Lāna'i, Oah'u, *Gardenia vitiensis,* Rubiaceae, Fiji, Vanua Levu, *Garnotia cheesemanii,* Poaceae, Cook Islands, Rarotonga, Te Manga track, *Garnotia sechellensis,* Poaceae, Seychelles, Morne Seychellois and Silhouette National Parks, *Geniostoma clavigerum,* Loganiaceae, Fiji, Mt. Evans and Mt. Lomalagi, *Geomitra coronula,* Hygromiidae, Portugal, Madeira Archipelago, Deserta Grande Island, *Geospiza heliobates,* Thraupidae, Ecuador, Galápagos Islands, Playa Tortuga Negra and Caleta Black, *Geothallus tuberosus,* Sphaerocarpaceae, USA, California, San Diego, *Geranium arboreum,* Geraniaceae, Hawaii, Maui, East Maui, Volcano Haleakalā, *Geranium maderense,* Geraniaceae, Portugal, Madeira, *Glaucidium mooreorum,* Strigidae, Brazil, Pernambuco Reserva, Biológica de Saltinho and Usina Trapiche, *Gleditsia vestita,* Fabaceae, China, Mt. Hengshan, *Globularia ascanii,* Globulariaceae, Spain, Canary Islands, Gran Canaria, Tamadaba, *Gocea ohridana,* Gastropoda, Hydrobiidae, Macedonia, Lake Ohrid, Velidab locality, *Goodyera macrophylla,* Orchidaceae, Portugal, Madeira, central and N parts, *Gouania meyenii,* Rhamnaceae, Hawaii, Kaua'i, O'ahu, *Gouania vitifolia,* Rhamnaceae, Hawaii, O'ahu, Hawai'i, *Gracupica jalla,* Sturnidae, Indonesia, Java, Bali, Sumatra (Lampung province), *Grallaria chthonia,* Grallariidae, Venezuela, SW Táchir, a El Tamá National Park, *Guaiacum unijugum,* Zygophyllaceae, Mexico, Baja California, *Guettarda wayaensis,* Rubiaceae, Fiji, Monuriki and Waya Island, Vanua Levu, *Haloragis stokesii,* Haloragaceae, Cook Islands, Rarotonga, Te Vaakauta, *Helichrysum nicolai,* Asteraceae, Cape Verde, São Nicolau Island, *Hemicycla modesta,* Helicidae, Spain, Canary Islands, Tenerife, Sta. Cruz, *Hesperomannia arbuscula,* Asteraceae, Hawaii, Maui, O'ahu, *Hibbertia favieri,* Dilleniaceae, New Caledonia, Plaine des lacs area, *Hibiscus clayi,* Malvaceae, Hawaii, Kaua'i, Nounou Mts, *Hibiscus fragilis,* Malvaceae, Mauritius, Garde Mtand Le Morne Brabant Mt., *Hildegardia populifolia,* Malvaceae, India, Andra Pradesh, Tamil Nadu, *Himantopus novaezelandiae,* Recurvirostridae, New Zealand, South Island, Waitaki Valley, *Holmskioldia gigas,* Lamiaceae, Tanzania, Ngarama Forest Reserve, *Horstrissea dolinicola,* Apiaceae, Greece, Mt. Ida, Psiloritis, *Hygrophila madurensis,* Acanthaceae, India, Tamil Nadu, Madurai, District Alagar Hills, *Hyophorbe amaricaulis,* Arecaceae, Mauritius, Curepipe Botanical Garden, *Hyophorbe lagenicaulis,* Arecaceae, Mauritius, Round Island, *Hyophorbe* *vaughanii,* Arecaceae, Mauritius, Macchabee Brise Fer Mare Longue Florin, *Hypochaeris oligocephala,* Asteraceae, Spain, Canary Islands, Tenerife, El Fraile, Buenavista, *Ilex khasiana,* Aquifoliaceae, India, Meghalaya, *Incilius holdridgei,* Bufonidae, Costa Rica, Cordillera Central, *Isodendrion pyrifolium,* Violaceae, Hawaii, O'ahu, *Isoetes wormaldii,* Isoëtaceae, South Africa, Eastern Cape, Grahamstown area, *Isothecium montanum,* Lembophyllaceae, Portugal, Madeira, Region of Pico, Ruivo and Pico do Areeiro, *Isthmohyla graceae,* Hylidae, Panama, Cordillera Central, Cerro Colorado, *Isthmohyla tica,* Hylidae, Costa Rica, and W Panama, Cordillera de Tilarán Cordillera Central and Cordillera de Tatamanca, *Jasminum azoricum,* Oleaceae, Portugal, Madeira, Funchal and Ribeira Brava, *Juncus maroccanus,* Juncaceae, Morocco, Ksar-el-Kebir region near Larache, *Keetia bakossii,* Rubiaceae, Cameroon, Bakossi Mts, *Keetia bakossiorum,* Rubiaceae, Cameroon, Bakossi Mts, *Labordia cyrtandrae,* Loganiaceae, Hawaii, O'ahu, *Lepilemur septentrionalis,* Lepilemuridae, Madagascar, Sahafary region, Madirobe and Ankarongana, *Lepiota rhodophylla,* Agaricaceae, USA, California, San Francisco Watershed, *Leptocereus grantianus,* Cactaceae, Puerto Rico, Culebra, *Leptocereus wrightii,* Cactaceae, Cuba, Havana city, Puerto Escondido, *Leptodon corsicus,* Leptodontaceae, France, Corsica, *Leptolaena masoalensis,* Sarcolaenaceae, Madagascar, Ambato-Masoala National Park, *Leucopsar rothschildi,* Sturnidae, Indonesia, Bali, Barat National Park, *Limonium dendroides,* Plumbaginaceae, Spain, Canary Islands, La Gomera, *Limonium jovibarba,* Plumbaginaceae, Cape Verde, Islands Monte Verde São Vicente and São Nicolau, *Limonium lobinii,* Plumbaginaceae, Cape Verde, Santiago Island, *Limonium sibthorpianum,* Plumbaginaceae, Italy, Sicily, Capo Alì, *Limonium sundingii,* Plumbaginaceae, Cape Verde, Islands Santiago, Island São Nicolau, *Lithocarpus formosanus,* Fagaceae, Taiwan, Pingtung County Kenting National Park, *Lobelia koolauensis,* Campanulaceae, Hawaii, O'ahu, *Lobelia monostachya,* Campanulaceae, Hawaii, O'ahu, *Lobelia oahuensis,* Campanulaceae, Hawaii, O'ahu, Wai'anae and Ko'olau Mts, *Lotus eremiticus,* Fabaceae, Spain, Canary Islands, La Palma, Garafia, *Lotus kunkelii,* Fabaceae, Spain, Canary Islands, Gran Canaria, Playa de Jinámar, *Lotus maculatus,* Fabaceae, Spain, Canary Islands, Tenerife, El Sauzal, *Magnistipula multinervia,* Chrysobalanaceae, Cameroon, Korup National Park, *Magnolia chimantensis,* Magnoliaceae, Colombia, Santander, and Venzuela, Chimantá, *Magnolia crassifolia,* Magnoliaceae, Ecuador, Los Encuentros, Jardin del Condor, *Magnolia fansipanensis,* Magnoliaceae, Vietnam, Hoang Lien National Park, *Magnolia grandis,* Magnoliaceae, China, Guangxi Yunnan, *Magnolia jardinensis,* Magnoliaceae, Colombia, Antioquia, *Magnolia longipedunculata,* Magnoliaceae, China, Guangdong, *Magnolia mayae,* Magnoliaceae, Mexico, Chiapas, and Guatemala, *Magnolia ovoidea,* Magnoliaceae, China, Yunnan, *Magnolia polyhypsophylla,* Magnoliaceae, Colombia, Antioquia, *Magnolia sinica,* Magnoliaceae, China, Yunnan, *Magnolia wolfii,* Magnoliaceae, Colombia, Risaralda, *Mammillaria glochidiata,* Cacteaceae, Mexico, Hidalgo, *Margaritifera marocana,* Margaritiferidae, Morocco, Oued Derna and Oued Beth, *Masoala madagascariensis,* Arecaceae, Madagascar, Mahavelona, Marojejy, *Meconopsis bhutanica,* Papaveraceae, Bhutan, Tshophu, Lake Soe Paro, *Megalochlamys tanaensis,* Acanthaceae, Kenya, Wema area, *Melanophylla angustior,* Torricelliaceae, Madagascar, Fianarantsoa, Manombo Special Reserve, *Melanthera kamolensis,* Asteraceae, Hawaii, Maui, *Melanthera micrantha,* Asteraceae, Hawaii, Kaua'i, *Melanthera waimeaensis,* Asteraceae, Hawaii, Kaua'i, Waimea Canyon, *Melicope adscendens,* Rutaceae, Hawaii, Maui, Haleakala, *Melicope knudsenii,* Rutaceae, Hawaii, Maui, Kaua'i, *Mellissia begonifolia,* Solanaceae, Saint Helena, *Memecylon myrtiforne,* Melastomataceae, Mauritius, Domain de Yemen, Grosse Roche, *Merulaxis stresemanni,* Rhinocryptidae, Brazil, Bahia Minas Gerais, *Meryta tenuifolia,* Araliaceae, Fiji, Viti Levu, *Mesua stylosa,* Calophyllaceae, Sri Lanka, W lowlands, *Metrosideros bartlettii,* Myrtaceae, New Zealand, North Island, Te Paki, *Mexipedium xerophyticum,* Orchidaceae, Mexico, Oaxaca, *Mezoneuron kavaiense,* Fabaceae, Hawaii, O'ahu, Hawai'i, *Mimus trifasciatus,* Mimidae, Ecuador, Galápagos Islands, *Monizia edulis,* Apiaceae, Portugal, Madeira, *Myrcia paganii,* Myrtaceae, Puerto Rico, *Myristica yunnanensis,* Myristicaceae, China, Yunnan, Xishuangbanna, *Myrmotherula snowi,* Thamnophilidae, Brazil, Frei Caneca Pedra Dantes, *Nannophryne cophotis,* Bufonidae, Peru, Regions of Ancash, Cajamarca, La Libertad, *Napaeus dolorosae,* Enidae, Spain, Canary Islands, La Gomera, Tagamiche Mt., *Nemosia rourei,* Thraupidae, Brazil, *Neophema chrysogaster,* Psittacidae, Australia, Tasmania, Melaleuca, *Neoschumannia kamerunensis,* Apocynaceae, Cameroon, Bakossi, Likombe Central Africa, Republic Dzanga-Sangha Reserve, *Neraudia sericea,* Urticaceae, Hawaii, Moloka'i, Maui, *Nesohedyotis arborea,* Rubiaceae, Ascension Islands, Saint Helena, and Tristan da Cunha, *Nomascus nasutus,* Hylobatidae, China, Vietnam, Trung Khanh District Cao Bang povince Phong Nam-Ngoc Khe Mts Guangxi, *Nothocestrum breviflorum,* Solanaceae, Hawaii, Hawai'i, Kohala, Mts. Hualalai, Mauna Loa, *Nothocestrum peltatum,* Solanaceae, Hawaii, Kaua'i, *Ochyraea tatrensis,* Amblystegiaceae, Slovakia, Nizke Tatry Mts., *Ocotea lancilimba,* Lauraceae, Mauritius, Gaullette, Serre and Montagne Cocotte, *Opuntia chaffeyi,* Cactaceae, Mexico, Zacatecas, *Orthotrichum handiense,* Orthotrichaceae, Spain, Canary Islands, Fuerteventura, *Ostrya rehderiana,* Betulaceae, China, Zhejiang Province, Tianmu Mt., *Oxygyne shinzatoi,* Thismiaceae, Japan, Ryukyu Islands, Okinawa Island, *Palaopartula calypso,* Partulidae, Palau, Babaldaob Koror, *Pandanus carmichaelii,* Pandanaceae, Mauritius, Le Petrin, *Pandanus microcarpus,* Pandanaceae, Mauritius, Perrier Henrietta Vallee de Couleurs Gavarnny, *Pandanus palustris,* Pandanaceae, Mauritius, Le Petrin, *Paphiopedilum bougainvilleanum,* Orchidaceae, Papua New Guinea, Bougainville Island, *Paphiopedilum canhii,* Orchidaceae, Vietnam, Dien Bien Phu province, *Paphiopedilum cornuatum,* Orchidaceae, China, Yunnan, Wuliang Shan Xiaojinggu, *Paphiopedilum dayanum*, Orchidaceae, Malaysia, Sabah, Borneo Mt. Kinabalu, *Paphiopedilum fairrieanum,* Orchidaceae, India, eastern Himalayas to Assam, *Paphiopedilum guangdongense,* Orchidaceae, China, *Paphiopedilum helenae,* Orchidaceae, China, Vietnam, Cao Banga Province, *Paphiopedilum inamorii,* Orchidaceae, Malaysia, Sipitang District, Mt. Rimau, *Paphiopedilum intaniae,* Orchidaceae, Indonesia, Sulawesi, *Paphiopedilum kolopakingii,* Orchidaceae, Indonesia, Borneo, *Paphiopedilum lawrenceanum,* Orchidaceae, Malaysia, Sabah, Mt. Kinabalu, *Paphiopedilum* *liemianum,* Orchidaceae, Indonesia, Sumatra, *Paphiopedilum ooii,* Orchidaceae, Malaysia, Sabah, Mt. Kinabalu, *Paphiopedilum platyphyllum,* Orchidaceae, Malaysia, Sarawak, *Paphiopedilum primulinum,* Orchidaceae, Indonesia, Sumatra, *Paphiopedilum qingyongii,* Orchidaceae, China, Tibet or Xizang, *Paphiopedilum rothschildianum,* Orchidaceae, Malaysia, Sabah, Mt. Kinabalu, *Paphiopedilum sanderianum,* Orchidaceae, Malaysia, Sarawak, *Paphiopedilum sangii,* Orchidaceae, Indonesia, Sulawesi, *Paphiopedilum schoseri,* Orchidaceae, Indonesia, Maluku, *Paphiopedilum sugiyamanum,* Orchidaceae, Malaysia, Sabah, *Paphiopedilum sukhakulii,* Orchidaceae, Thailand, Phu Luang Mountains, *Paphiopedilum thaianum,* Orchidaceae, Thailand, Phangnga province, *Paphiopedilum tranlienianum,* Orchidaceae, Vietnam, Thai Nguyen and Tuyen, *Paphiopedilum urbanianum,* Orchidaceae, Philippines, Mindoro Island, *Paphiopedilum victoria-mariae,* Orchidaceae, Indonesia, Sumatra, *Paphiopedilum victoria-regina,* Orchidaceae, Indonesia, Sumatra, *Paphiopedilum wenshanense,* Orchidaceae, China, Yunnan, *Partula emersoni,* Partulidae, Micronesia, Pohnpei Island, *Partula meyeri,* Partulidae, French Polynesia, Raiatea, *Peniocereus maculatus,* Cactaceae, Mexico, Guerrero, *Peniocereus occidentalis,* Cactaceae, Mexico, Oaxaca, *Peniocereus zopilotensis,* Cactaceae, Mexico, Guerrero, *Pennantia baylisiana,* Pennantiaceae, New Zealand, Great Island Manawa, *Pericallis hadrosoma,* Asteraceae, Spain, Canary Islands, Gran Canaria, *Peristylus holochila,* Orchidaceae, Hawaii, Kaua'i, Moloka'i, Maui, *Phalaenopsis micholitzii,* Orchidaceae, Philippines, Luzon and Mindanao, *Phaseolus lignosus,* Fabaceae, Bermuda, Nature Reserve Walsingham Sear's Cave Gladys Morrell & Nonsuch Island, *Phlegmariurus nutans,* Lycopodiaceae, Hawaii, O'ahu, *Phocoena sinus,* Phocoenidae, Mexico, Gulf of California, Baja California, *Phragmipedium andreettae,* Orchidaceae, Colombia, Ecuador, W cordillera of the Andes, *Phragmipedium anguloi,* Orchidaceae, Colombia, W Andes, Patia-Timbio valley, *Phragmipedium dalessandroi,* Orchidaceae, Ecuador, Rio Bombuscarua, *Phragmipedium exstaminodium,* Orchidaceae, Mexico, Chiapas, *Phragmipedium kovachii,* Orchidaceae, Peru, Amazonas department, *Phragmipedium manzurii,* Orchidaceae, Colombia, Santander province, *Phylica polifolia,* Rhamnaceae, Saint Helena, Island summit of Lot High Hill and Ebony Point, *Phyllanthus kidna,* Phyllanthaceae, Cameroon, Yaoundé Mefou proposed National, *Phyllanthus revaughanii,* Phyllanthaceae, Mauritius, Ilot, Bernache Round island Ile aux Aigrettes, *Phyllostegia haliakalae,* Lamiaceae, Hawaii, Lana'i, Moloka'i, Maui, *Phyllostegia helleri,* Lamiaceae, Hawaii, Kaua'i, *Phyllostegia hirsuta,* Lamiaceae, Hawaii, O'ahu, *Phyllostegia hispida,* Lamiaceae, Hawaii, Moloka'i, *Phyllostegia kaalaensis,* Lamiaceae, Hawaii, O'ahu, *Phyllostegia mollis,* Lamiaceae, Hawaii, O'ahu, *Phyllostegia warshaueri,* Lamiaceae, Hawaii, Kaua'i, *Phyllostegia wawrana,* Lamiaceae, Hawaii, Kaua'i, *Pilea cataractae,* Urticaceae, Mauritius, Tamarin Falls, *Pilosocereus diersianus,* Cactaceae, Brazil, Goiás, *Pilosocereus frewenii,* Cactaceae, Brazil, Minas Gerais, *Pinus squamata,* Pinaceae, China, Yunnan, *Pittosporum brevispinum,* Pittosporaceae, New Caledonia, Pouembout area, *Pittosporum coriaceum,* Pittosporaceae, Portugal, Madeira, *Pittosporum sp. nov. 'veilloniana',* Pittosporaceae, New Caledonia, *Pittosporum tanianum,* Pittosporaceae, New Caledonia, île Léprédour, *Pleodendron macranthum,* Canellaceae, Puerto Rico, El Yunque, *Plerandra sp. nov. "mackeei",* Araliaceae, New Caledonia, Pouembout, *Poa riphaea,* Poaceae, Czech Republic, *Podonephelium parvifolium,* Sapindaceae, New Caledonia, Grande Terre, *Polyscias bisattenuata,* Araliaceae, Hawaii, Kaua'i, *Polyscias flynnii,* Araliaceae, Hawaii, Kaua'i, *Polyscias gruschvitzkii,* Araliaceae, Madagascar, Toamasina, *Polyscias lionnetii,* Araliaceae, Seychelles, Mahé Islands, *Polyscias rodriguesiana,* Araliaceae, Mauritius, Rodrigues, *Polyspora dassanayakei,* Theaceae, Sri Lanka, Badulla Kandy District Eliya, *Polyspora gioii,* Theaceae, Vietnam, Khánh, Hòa Province, *Polystichum drepanum,* Dryopteridaceae, Portugal, Madeira, *Pomarea nigra,* Monarchidae, French Polynesia, Tahiti, *Pomarea whitneyi,* Monarchidae, French Polynesia, Fatu, Hiva, *Populus berkarensis,* Salicaceae, Kazakhstan, Karatau Mts., *Porites pukoensis,* Poritidae, Hawaii, Molokai Island, *Potorous gilbertii,* Potoroidae, Australia, Mount Gardner, Two peoples Bay Reserve, *Prasophyllum favonium,* Orchidaceae, Australia, Tasmania, *Primulina modesta,* Gesneriaceae, Vietnam, Halong Bay, *Pritchardia hardyi,* Arecaceae, Hawaii, Kaua'i, *Pritchardia munroi,* Arecaceae, Hawaii, *Pritchardia schattaueri,* Arecaceae, Hawaii, *Pritchardia viscosa,* Arecaceae, Hawaii, Kaua'i, *Prospero talosii,* Asparagaceae, Greece, Dia, Island Natura 2000, *Psephurus gladius,* Polyodontidae, China, Yangtze River, *Pseudolmedia manabiensis,* Moraceae, Ecuador, Cerro Montecristi, *Psiadia cataractae,* Asteraceae, Mauritius, *Psychotria silhouettae,* Rubiaceae, Seychelles, Silhouette Island, *Pteris lidgatei,* Pteridaceae, Hawaii, O'ahu, Maui, Moloka'i, *Pyrenaria buisanensis,* Theaceae, Taiwan, Pingtung County in Taiwan, *Pyrenaria cherrapunjeana,* Theaceae, India, Meghalaya, Khasi Hills, *Pyrus gergerana,* Rosaceae, Armenia, Ger Ger village, *Rafetus swinhoei,* Trionychidae, Vietnam, Hoan Kiem Lake and Dong Mo Lake, *Rafflesia magnifica,* Rafflesiaceae, Philippines, Mindanao Island, *Ramosmania rodriguesii,* Rubiaceae, Mauritius, Rodrigues, *Rapanea seychellarum,* Myrsinaceae, Seychelles, Mahé Silhouette and Praslin, *Ravenea beentjei,* Arecaceae, Madagascar, Vondrozo, *Ravenea delicatula,* Arecaceae, Madagascar, Andilamena, *Ravenea hypoleuca,* Arecaceae, Madagascar, Vondrozo and Tsitongambarika, *Ravenea lakatra,* Arecaceae, Madagascar, between Masoala and Vangaindrano, *Ravenea louvelii,* Arecaceae, Madagascar, Andasibe, *Rhamnus lojaconoi,* Rhamnaceae, Italy, Sicily, *Ribes sardoum,* Grossulariaceae, Italy, Sardinia, Nuoro Province, *Risiocnemis seidenschwarzi,* Platycnemididae, Philippines, Cebu Island, Kawasan River, *Romulea antiatlantica,* Iridaceae, Morocco, Anti Atlas Mts., *Romulea villaretii,* Iridaceae, Morocco, Anti Atlas Mts., *Rorippa valdes-bermejoi,* Brassicaceae, Spain, Huelva Parque Nacional, *Rosa dolichocarpa,* Rosaceae, Russia, Federation Stavropol Krai, *Rubus rugulosus,* Rosacea, Sweden, Halland around Rydet Onsala, *Saintpaulia ulugurensis,* Gesneriaceae, Tanzania, North Uluguru Mts., *Saintpaulia watkinsii,* Gesneriaceae, Tanzania, North Uluguru Mts., *Sanicula mariversa,* Apiaceae, Hawaii, O'ahu, *Santamartamys rufodorsalis,* Echimyidae, Colombia, Sierra Nevada de Santa Marta el dorade Nature Reserve, *Sarcolaena isaloensis,* Sarcolaenaceae, Madagascar, Isalo National Parc, *Saribus jeanneneyi,* Arecaceae, New Caledonia, Grande Terre, *Scalesia atractyloides,* Asteraceae, Ecuador, Galápagos Islands, Santiago

Island, *Schiedea adamantis,* Caryophyllaceae, Hawaii, O'ahu, *Schiedea kaalae,* Caryophyllaceae, Hawaii, O'ahu, *Schiedea membranacea,* Caryophyllaceae, Hawaii, Kaua'i, *Schiedea nuttallii,* Caryophyllaceae, Hawaii, O'ahu, *Sclerotheca viridiflora,* Campanulaceae, Cook Islands, Rarotonga, *Semperdon xyleborus,* Charopidae, Palau, *Senecio lamarckianus,* Asteraceae, Mauritius, *Serratorotula acarinata,* Hygromiidae, Portugal, Madeira, Ilhéu de Baixo Rede de Áreas Marinhas, *Silene alexandri,* Caryophyllaceae, Hawaii, Moloka'i, *Simirestis klaineana,* Celastraceae, Gabon, Province de l'Estuaire, *Sinapidendron rupestre,* Brassicaceae, Portugal, Madeira, *Sitta insularis,* Sittidae, Bahamas, Grand Bahama Island, *Solanum incompletum,* Solanaceae, Hawaii, Hawai'i, mountain range, *Solenanthus reverchonii,* Boraginaceae, Spain, Cabrilla, *Sonneratia hainanensis,* Lythraceae, China, Hanan, Wenchang County, *Sorbus acutiserrata,* Rosaceae, Hungary, Gánt Vértes Mts., *Sorbus adamii,* Rosaceae, Hungary, Gánt Vértes Mts., *Sorbus algoviensis,* Rosaceae, Germany, Bavaria, *Sorbus arvonensis,* Rosaceae, UK, Great Britain, Wales Strait, *Sorbus atrimontis,* Rosaceae, Slovakia, Carpathian Mountain chain Veľká Natura 2000, *Sorbus avonensis,* Rosaceae, UK, Great Britain, Avon, *Sorbus bakonyensis,* Rosaceae, Hungary, Bakony Mts., *Sorbus borosiana,* Rosaceae, Hungary, Vértes Mts., *Sorbus busambarensis,* Rosaceae, Italy, Sicily, Rocca Busambra, *Sorbus cheddarensis,* Rosaceae, UK, Great Britain, England, *Sorbus dracofolia,* Rosaceae, Hungary, Gánt, Vértes Mts., *Sorbus eminentoides,* Rosaceae, UK, Great Britain, England, *Sorbus evansii,* Rosaceae, UK, Great Britain, England, Gloucestershire, *Sorbus eystettensis,* Rosaceae, Germany, Bavaria, *Sorbus gauckleri,* Rosaceae, Germany, Bavaria, *Sorbus greenii,* Rosaceae, UK, Great Britain, England, *Sorbus harziana,* Rosaceae, Germany, Bavaria, *Sorbus herbipolitana,* Rosaceae, Germany, Bavaria, *Sorbus hohenesteri,* Rosaceae, Germany, Bavaria, Leutenbach, *Sorbus holubyana,* Rosaceae, Slovakia, Malé, Karpatý Mts. Čachtické Hills, *Sorbus kmetiana,* Rosaceae, Slovakia, Malé, Karpatý Mts. Čachtické Hills, *Sorbus leyana,* Rosaceae, UK, Great Britain, Wales, *Sorbus lonetalensis,* Rosaceae, Germany, Bissingen, *Sorbus meierottii,* Rosaceae, Germany, Bavaria, Wellheim, *Sorbus mergenthaleriana,* Rosaceae, Germany, Bavaria, Regensburg, *Sorbus milensis,* Rosaceae, Czech Republic, Central Bohemian, Uplands České středohoří, *Sorbus parviloba,* Rosaceae, UK, Great Britain, England Gloucestershire, *Sorbus pauca,* Rosaceae, Czech Republic, N Doksy region, *Sorbus perlonga,* Rosaceae, Germany, Bavaria, Würzburg, *Sorbus pontis-satanae,* Rosaceae, Czech Republic, Brno, Moravian Karst, *Sorbus portae-bohemicae,* Rosaceae, Czech Republic, České středohoří Mts., *Sorbus pseudomeinichii,* Rosaceae, UK, Great Britain, Scotland, Arran Glen Catacol, *Sorbus pulchra,* Rosaceae, Germany, Bavaria, *Sorbus pyricarpa,* Rosaceae, Hungary, Vértes Mts., *Sorbus richii,* Rosaceae, UK, Great Britain, England Estuary, *Sorbus rupicoloides,* Rosaceae, UK, Great Britain, England, *Sorbus salatin,* Rosaceae, Slovakia, Nízke Tatry Mts., *Sorbus saxicola,* Rosaceae, UK, Great Britain, Wales, England, *Sorbus scannelliana,* Rosaceae, Ireland, Island Killarney, *Sorbus scepusiensis,* Rosaceae, Slovakia, Volovské vrchy, *Sorbus schnizleiniana,* Rosaceae, Germany, Bavaria, Neukirchen/Sulzbach-Rosenberg, *Sorbus schuwerkiorum,* Rosaceae, Germany, Bavaria, *Sorbus schwarziana,* Rosaceae, Germany, Bavaria, *Sorbus seyboldiana,* Rosaceae, Germany, Baden-Württemberg, Bavaria, *Sorbus spectans,* Rosaceae, UK, Great Britain, England, Gorge, *Sorbus stirtoniana,* Rosaceae, UK, Great Britain, Wales, Breidden, *Sorbus thayensis,* Rosaceae, Austria, Czech Republic, Dyje River, *Sorbus tobani,* Rosaceae, Hungary, Bakony Mts., *Sorbus ujhelyii,* Rosaceae, Hungary, Transdanubian Mts., *Sorbus vallerubusensis,* Rosaceae, Hungary, Vértes Mts., *Sorbus vexans,* Rosaceae, UK, Great Britain, England, *Sorbus whiteana,* Rosaceae, UK, Great Britain, England, Valley Avon Gorge, *Sorbus zertovae,* Rosaceae, Slovakia, Malé, Karpaty Mountains, Trnava Senica District, *Stenocereus chacalapensis,* Cactaceae, Mexico, Oaxaca, *Stenogyne kealiae,* Lamiaceae, Hawaii, Kaua'i, *Styrax portoricensis,* Styracaceae, Puerto Rico, Caribbean National Forest, *Syagrus werdermannii,* Arecaceae, Brazil, state of Bahia Caetité, *Syzygium guehoi,* Myrtaceae, Mauritius, Magenta Mt., *Tahina spectabilis,* Arecaceae, Madagascar, Analalava district, *Tambourissa cocottensis,* Monimiaceae, Mauritius, Montagne cocotte, *Tambourissa pedicellata,* Monimiaceae, Mauritius, Mt. Lagrave Macchabee Bassin, *Tanacetum oshanahanii,* Asteraceae, Spain, Canary Islands, Gran Canaria, Gran Canaria de Guayedra, *Tarenna hutchinsonii,* Rubiaceae, Guinea, and Liberia, Guinea Forestiére, *Ternstroemia bullata,* Pentaphylacaceae, Jamaica, Clarendon, *Ternstroemia glomerata,* Pentaphylacaceae, Jamaica, Clarendon, *Ternstroemia luquillensis,* Pentaphylacaceae, Puerto Rico, *Ternstroemia subsessilis,* Pentaphylacaceae, Puerto Rico, Caribbean National Forest Rivera, *Tetrataxis salicifolia,* Lythraceae, Mauritius, Cascade Cinq Cent Pieds Le Pouce, *Teucrium abutiloides,* Lamiaceae, Portugal, Madeira, *Thamnobryum angustifolium,* Neckeraceae, UK, Great Britain, England, Carlisle and Peak District, *Thamnobryum cataractarum,* Neckeraceae, UK, Great Britain, England, Yorkshire, *Thlaspi zangezuricum,* Brassicacea, Armenia, Zangezur and Megri floristic, *Tinadendron noumeanum,* Rubiaceae, New Caledonia, Noumea Tina Bay, *Toxostoma guttatum,* Mimidae, Mexico, Cozumel Island, *Trichilia triacantha,* Meliaceae, Puerto Rico, Guanica Forest and Boqueron, *Trilepisium gymnandrum,* Moraceae, Seychelles, Silhouette National Park, *Trochetiopsis ebenus,* Malvaceae, Ascension Island, Tristan da Cunha, *Turbina inopinata,* Convolvulaceae, New Caledonia, Paita Pouembout, *Ulmus gaussenii,* Ulmaceae, China, Anhui, *Urera kaalae,* Urticaceae, Hawaii, O'ahu, Waianae Mts., *Vangueriopsis shimbaensis,* Rubiaceae, Kenya, Shimba Hills National reserve, *Varronia bellonis,* Cordiaceae, Puerto Rico, Maricao, Río Abajo Ciales and Utuado, *Vateriopsis seychellarum,* Dipterocarpaceae, Seychelles, Morne, Seychellois National Park, *Verbascum transcaucasicum,* Scrophulariaceae, Turkey, Anatolia, Kars, *Vicia ferreirensis,* Fabaceae, Portugal, Madeira, Porto Santo Island, *Vicia menziesii,* Fabaceae, Hawaii, Hawai'i, Mauna Loa, *Videna pumila,* Trochomorphidae, Palau, Peleliu Island, *Voanioala gerardii,* Arecaceae, Madagascar, Bay of Antongil, *Warneckea ngutiensis,* Melastomataceae, Cameroon, Nguti Banyang Mbo forest, *Weberocereus frohningiorum,* Cactaceae, Costa Rica, San José, *Weinmannia exigua,* Cunoniaceae, Fiji, Vanua Levu, *Wikstroemia villosa,* Thymelaeaceae, Hawaii, Maui, *Xylopia amplexicaulis,* Annonaceae, Mauritius, Macchabe, Mare Longue, Plateau Brise Fer Ridge, *Xylopia lamarckii,* Annonaceae, Mauritius, Macchabe, Longue, *Xylosma crenatum,* Salicaceae, Hawaii, Nualolo Trail, Kokee, State Park Napalikona Forest Reserve, *Zamia restrepoi,* Zamiaceae, Colombia, Cordoba Urra, *Zeuxine rolfiana,* Orchidaceae, India, Andaman, Nicobar Islands, *Zoogoneticus tequila,* Goodeidae, Mexico, Rio Ameca drainage, Teuchitlan River, *Zornia vaughaniana,* Fabaceae, Mauritius, Ilot Sanchot, Riviere des Gallets, *Zosterops nehrkorni,* Zosteropidae, Indonesia, Sulawesi, Sangihe.

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Coastal Habitats, Shallow Seas and Inland Saline Steppes: Ecology, Distribution, Threats and Challenges

Carsten Hobohm, Joop Schaminée, and Nils van Rooijen

Abstract Coastal and inland saline habitats are distributed worldwide. The coastal habitats occur at the border between land and sea in various landscape formations, such as rocky shores, shallow coasts and protected bays, as far as to offshore areas. The inland saline habitats are predominantly part of inland steppe ecosystems. The complex underlying geomorphology, ecology, specialized flora and fauna, temporal and spatial dynamic, diverse ecosystem services and the general importance for human populations, settlements, fisheries, trades, and tourism make coastal habitats a unique part of the world's landscape.

In this chapter, we briefly outline the historic significance of coastal habitats and their ecosystem functions and services. We describe recent threats affecting coastal habitats and their flora and fauna. Owing to their spatially close relation or similarities in vegetation composition to saltmarshes, we additionally describe the characteristics of shallow sea communities and inland saline steppe vegetation.

Today, many of the characteristic plant and animal species showing special adaptations with respect to challenging environmental, as well as subtidal, coastal and inland saline habitats are threatened worldwide and thus, are under serious pressure. Main threats comprise residential and commercial building development, artificial coastal defence, tourism, overexploitation, pollution, increasing pressure of invasive and other problematic species, anthropogenic influence on water dynamics and climate-change induced changes in coastal dynamics.

Theoretically, many climate-related extremes such as floods and hurricanes imply a much higher risk for humans and human buildings at the coast than for natural

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habitats which evolved under dynamic conditions and are adopted to strong coastal wind and water dynamics. However, as the natural resilience of these habitats is now often impaired by anthropogenic factors and climate extremes facilitate previously unknown variation to natural dynamics, climate change has become a growing threat to coastal ecosystems.

We outline past and currently applied projects and activities, which we perceive as promising examples of science-based nature conservation measures in relation to main threats and socio-economic issues. We conclude with discussing future perspectives of coastal habitats on global and regional scale, in the light of global change, i.e. human influence on natural dynamics, land use change, climate change, and coastal protection.

Solutions to reduce the pressure on coastal habitats and biota comprise, among others, e.g. to enlarge nature reserves and zero-use zones, to reduce human impact at landscape scales, and to give space for natural dynamics. Pollution and the impact of fertilizers may be locally reduced by buffer zones and technological solutions. However, the local interest in reducing sewage and nutrient release can only be limited by national or supra-national recycling policies and related regulations.

One of the problems which cannot easily be solved is the irreversible introduction of alien species. Invasion of native biota can also become a problem if environmental conditions are altered. In this case every problem has to be monitored at regional scales and managed by hand, if possible.

At the same time, we assume that current tendencies, e.g. growing settlements and cities at the coasts, increasing tourism and climate change cannot be reversed in a short time.

Furthermore, political decisions are often unpredictable.

Keywords Coastal cliffs · Coastal habitats · Dunes · Ecosystem functions · Inland saline habitats · Mangroves · Coral reefs · Saltmarshes · Seagrass beds · Subtidal habitats · Threats

1 Introduction

The term *coastal habitats* comprise all habitat types found within the transition zone between land and sea. It refers to diverse ecosystems within the shallow subtidal and intertidal zone. At the terrestrial side, these often relatively narrow strips are naturally bordered by rock formations, sea cliffs and, in more gradual transitions situations, by sand dunes (supratidal zone) or saltmarshes. The coastal landscape as such include coral reefs, seagrass beds, mangroves, saltmarshes, algal communities including "*giant kelp forests*" (Schiel and Foster 2015), lichen and vascular plant communities of rocky shores and sea cliffs, as well as sandy dune habitats in diverse stages of development. Although natural coastal landscapes only cover a small percentage of the Earth's surface, they are unique ecosystems with a highly diverse flora and fauna.

The coastal landscape is subject to intense spatial and temporal dynamics, most strongly influenced by flooding and aeolian dynamics, fluctuating salinity, and succession processes. Flora and fauna are specifically adapted to these processes. The availability of various niches related to strong gradients in abiotic and biotic conditions make the coastal landscape one of the most biodiverse systems on our planet, of which still a lot is unknown. Moreover, coastal ecosystems are highly interconnected, at local as well as at global scales. Changing conditions and processes in one place, may affect coastal habitats thousands of kilometres away.

Since very long times, coastal landscapes, shallow waters along the shoreline and estuaries belong to the important regions for human society, offering various ecosystem services However, in recent times, characteristic coastal ecosystems undergo a dramatically decline in quality and quantity (Janssen et al. 2016), although their values and threats have been noted already for a long time (Jefferies and Davy 1979; Westhoff 1985; Duarte et al. 2008; Nellemann et al. 2009; Vierros 2017). They occur under serious pressure through various—mostly human-induced—threats adversely altering abiotic and biotic conditions. These threats include land-use intensification as well as abandonment, land reclamation (Spalding et al. 2014), large-scale destructions for industrial, artificial coastal defence, harbour and commercial purposes, residential and commercial building development, tourism, extraction of oil, gas and drinking water, pollution, increasing pressure of invasive and other problematic species, sea-level rise, and the increase of climate-related extremes. Many of the artificial conversions of coastlines obstruct natural dynamics and may lead to dysfunctions in sediment availability and the interruption of alongshore sediment transport. Furthermore, the introduction of—often invasive—alien species is becoming a serious threat, for native species and communities. Dune protection went along with over-stabilization of the remaining complexes by planting trees and huge amounts of Marram grass (*Ammophila arenaria*; Martínez et al. 2013).

Some of the coastal habitats, e.g. saline shrubland or saltmarshes, may be less charismatic than other habitats, e.g. coral reefs, which leads to a decrease in public awareness of their losses, results in the continuation of detrimental practices and thus, contributes to their continued decline. More effective communication of scientific knowledge about these assumed uncharismatic, but ecologically important coastal habitats is required (Duarte et al. 2008).

In the following, we describe and analyse recent environmental conditions and challenges of subtidal, intertidal, supratidal (terrestrial) as well as inland saline habitats, which in comparison with saltmarshes reflect quite similar ecological conditions and species compositions. We quantify the pressure on the flora and fauna of coastal habitats in different regions, habitat types and taxonomic groups. Furthermore, we present selected examples of effective nature conservation concepts and measures. As climate-change induced changes in coastal dynamics, such as severe floods and hurricanes represent an increasing threat for uninhabited as well as populated coastlines, we conclude with a brief discussion on nature-based solutions, which may offer new opportunities for coastal defence.

2 Historical Meaning and Ecosystem Services

Archaeological findings in Israel, located at the shore of the Sea of Galilee, and in a near-coastal site on Triquet Island in British Columbia, belong to the oldest human settlements in the world, dating back to about 19,500 and 14,000 years BP, long before agriculture was invented. In more or less the same period, the first evidence of human fishing has been detected (e.g. Presland 1997; Blainey 2004; Mcintosh 2009). These old settlements and the recent position of cities in the world indicate the preference of humans for the proximity to coastal landscapes and freshwater habitats. However, since the sea level during the Last Glacial Maximum (c. 30–16,000 years ago) has risen by 120–140 m, it can be assumed that most of the old settlements at the coasts are inundated today. Meanwhile, many offshore artefacts, ruins and artificial structures have been secured, indicating submerged settlements that are several thousand years old (Badrinaryan 2006).

Coastal habitats played a central part in many societies as they offer access to food resources (e.g. fish, seafood) and provide manifold additional ecosystem services, such as water purification, preservation of genetic diversity, coastal defence or recreation improving quality of human life (e.g. Willaert et al. 2019). Thus, the resilient and long-term stable occurrence is of considerable importance for the longevity of our coastal landscape and its intrinsic natural and cultural value. However, current activities, including exploitation of coastal resources and the construction of artificial barriers are rapidly threatening these services. Coastal cities and industries strongly decrease the area for natural habitat and emit light, noise and toxic substances. Today, more and more people live in large cities and settlements at the coasts. Furthermore, an increasing number of people is attracted by beaches during holiday. Sea harbours became gateways for trade and exploration, but also for invasive species. People are flying around the world to visit coastal cities, coastal beaches and other scenic landscapes, for sunbathing, diving, reef-, wale- and birdwatching, to eat fresh fish, or simply to go shopping. As a consequence, many coastal regions are dramatically impacted by human activities, wastewater, plastic or other kinds of pollution, and the pressure to certain habitat types and species populations is extremely high.

The hilly landscape of sand dunes provided shelter against winds and flooding from the seaside. In the past, small-scale agriculture could be performed in dune systems, and dune grasslands were used for the maintenance of fishing gear and bleaching of linen. These small disturbances, that locally increased biodiversity, are still visible in the species-rich vegetation near the Sea villages in the Netherlands and Belgium or in the calcareous *machair* grasslands in Ireland and Scotland. The large volume of sand harbours huge fresh water supplies and till now drinking water companies provide dune filtered water to millions of people (van Rooijen and Schaminée 2014).

Other coastal habitats also provide ecosystem services of high economic value. For example, since more than a century, coastal wetlands have been recognized for their ability to stabilize shorelines and to protect coastal communities. Saltmarshes and mangroves are able to reduce wave heights, property damage and human deaths (Jin-Eong 2004; Gedan et al. 2011). Particularly coral reefs, mangroves, seagrass meadows and saltmarshes capture and store huge amounts of carbon, up to 50% of all carbon sequestered in marine sediments (Union et al. 2005). Costanza et al. (1997) mention it has been estimated that coastal habitats deliver the highest annual value, in terms of ecosystem services, of all-natural ecosystems on the planet. This is in strong contrast with their conservation states, as these ecosystems are being degraded and disappear at rates five to ten times faster than rainforests (Nellemann et al. 2009). An open dialogue between scientists, conservation practitioners and policy makers is urgently needed on the national and international level and with respect to global change (Vierros 2017).

Today, more and more people live in large cities and settlements at the coasts. Furthermore, an increasing number of people is attracted by beaches, dunes and warm water during holiday. People are visiting scenic places at the coast, e.g. for sunbathing, swimming, diving, reef-, wale- and birdwatching, or simply relaxation. Thus, tourism to coastal areas such as beaches implies both economical attractivity and pressure to natural systems (Martínez et al. 2013).

3 Selected Habitat Types

Coastal habitats can be classified in relation to landscape formation and genesis (geomorphology, e.g. Valentin 1952; Owens 1994) which provides a sound basis for other ways of classifying coastal landscapes (Finkl 2004).

Apart from submerged algae in the sub- and intertidal zones, coastal vegetation requires moderate water conditions and a relatively high substrate stability, ranging from seagrass beds on mud flats, algal, lichen and vascular plant communities on rocky shores, productive saltmarshes, halophytic shrubland and (tropical) mangroves, as well as more or less open grassland of coastal dunes. Everywhere, the vegetation interacts with water conditions and sediments, and therefore are often used for habitat classification. As such, coastal habitats can be classified with respect to water depth, duration of inundation, proximity to the shoreline, salt content, type of substrate, and geomorphology, among others. They often undergo strong spatial and temporal dynamics, strongly influenced by wind and water, flooding, salinity, and periodicity of drought and precipitation. The flora and fauna in these habitats are often highly adapted to dynamic habitats. Unvegetated habitats of the sublittoral and littoral zones can be classified by substrate, e.g. rocky ground, gravel, sand or clay, or by the time of inundation (Goetting et al. 1988; IUCN 2019). Parts of the beaches and rocky shores which are inundated during high tides belong to the intertidal zone, higher elevated parts or areas which are not flooded on a regular basis, belong to the supratidal zone.

The classification of coastal vegetated habitats is furthermore supported by the underlying substrate, location in relation to the water level or in proximity to the shoreline, and salinity. Going more into detail, dynamic processes such as the force of the coastal surf and currents, the characteristic of the tidal system, and fluctuations in sea level help to refine basic classification schemes. Transnational schemes of classifications on habitat or plant community level and with respect to biogeography, ecology, structure and species composition have been published by, among others, Davies et al. (2004), Janssen et al. (2016), IUCN (2019), and Pätsch et al. (2019).

Plant communities at the coast with the same structure and a comparable species composition may be called *saltmarsh.* These are generally assigned to specific coastal vegetation units, whereas their inland counterpart, called *salt steppes*, are mostly assigned to grasslands. Like other names for habitat types or vegetation units, many of them are defined in different ways. Moreover, different names are sometimes used for the same unit. Therefore, we try to unify the terminology.

With respect to the mentioned classification schemes, related groups of habitats can be ordered as described in Table 1.

In the following, we briefly consider environmental conditions including human influence of selected habitat types from the marine environment to the shoreline, and from coast to inland.

3.1 Coral Reefs

Corals are marine invertebrates (*Anthozoa*). Many of them use the photosynthesis of symbiotic microscopic algae (*Zooxanthellae*). Therefore, they need sunlight and prefer clear water. However, nearly as many deep-water coral species without symbiotic algae exist. Corals, algae and sponges are reef-building organisms. Most reefs occur in shallow tropical marine environments between latitudes 38° N and 25° S. Deep and cold water coral and sponge reefs, bioherms or banks exist to a smaller extent outside of the Tropics, for example in the North Atlantic, Canadian Arctic and Antarctic continental shelves (Freiwald and Roberts 2006).

All these systems provide habitat to a multitude of other species and are rich e.g. in terms of fish, mollusc, crustacean, echinoderm, sponge, and tunicate species. They cover less than 0.1% of the marine ground. However, it is estimated that they harbour round about a quarter of all marine species (Murphy 2002; Hopley 2011). Coral reefs have an important function as fish nurseries and are therefore, ecologically, closely linked to other coastal habitats (Unsworth et al. 2008).

Damage and decline of coral reefs are caused by destructive fishing, tourism, land-based pollution and runoff, and climate effects including severe weather, temperature stress and coral bleaching (Cesar et al. 2003; Rinkevich 2008). Interactions within the disturbance factors often lead to an exacerbation of the situation (Ellis et al. 2019). Coral reefs belong to the most charismatic ecosystems in the world. The attraction to humans results in a massive coral reef tourism. This has both effects positive and negative ones. The recent challenge is to intensify nature conservation efforts and to reduce disturbance (Lirman and Schopmeyer 2016; Finea et al. 2019).

Table 1 Overview of coastal and inland saline habitats

Environment	Habitat
Subtidal (near-coastal, shallow, permanently submerged)	Rock; Sand; Mud; Coral reefs; Macroalgal/kelp; Seagrass beds (submerged)
Marine intertidal (between high and low spring tide)	Seagrass beds (regularly inundated); Rocky ground with/without algae, lichens, barnacles or others; Sandy beach (SiO_2, coral sand, other), gravel beach, shingle beach; Clay/mud and/or peat flats; Drift line with/without characteristic vegetation; Saltmarsh (dominated by grasses and herbs, grassland or steppe habit); Swamp/reed; Halophytic shrubland; Mangrove
Coastal supratidal (not inundated normally, occasionally influence of salt spray)	Rock pool; High elevated beach; Dune without vegetation; Pioneer vegetation; Closed dune grassland vegetation dominated by grasses, herbs, bryophytes, and/or lichens; Dune dominated by shrubs; Machair, Zeedorpenlandschap (coastal plain with sand and shell sediment, characteristic vegetation and use); Dune valley; Inundated or (seasonally) wet dune slack; Sea cliff/rocky shore
Inland saline (separated from the sea/coast)	Unvegetated; Salt lake (permanent inundated or seasonally dry); Salt steppe Swamp/reed; Halophytic shrubland

3.2 *Tidal Flats*

Intertidal mud flats occur in sheltered areas, where finer sediments can deposit. Each tide new sediments are brought in or washed out, creating an environment shaped by tidal cycles. The deep muddy sediment offers a habitat for a variety of species of molluscs, worms, crustaceans and other invertebrates which are often extremely abundant. Therefore, these ecosystems are important feeding grounds for fish and especially for birds. Many millions of migratory birds, migrate via these muddy ecosystems to forage. Large areas of mud flats are rare, but combined mud flats form an extensive coastal habitat of almost 128,000 km^2 (Murray et al. 2019). The only natural hard substrate in these systems are mussel or oyster beds, which give shelter to many other species.

Apart from algae, often attached to hard substrate such as mussel, or oyster banks, sea grasses (*Zosteraceae*, *Posidoniaceae and Cymodoceaceae*) can grow on mud flats of shallow subtidal and intertidal substrates. In well-functioning sea grass beds, the vegetation forms a semi-open self-organized vegetation, caused by nutrients and sediment availability, much alike mussel banks. Here eel grass species (*Zostera*) form a symbiosis with other biota in the soil (Van der Heide et al. 2012).

3.3 Mangroves

Mangroves are woody habitats of saline and brackish lagoons, shorelines and estuaries between latitudes 25° N and 25° S (e.g. Fig. 1). Substrates are often muddy or sandy, less often stony or rocky, and normally located at the transition between low and high tide. The habitat is often characterized by deposition of fine sediments with high proportion of organic material (Bowen et al. 2001; Jin-Eong 2004; Spalding et al. 2010).

In general, the composition of vascular plants is rather species-poor whereas the water fauna can be classified as relatively species-rich (Goetting et al. 1988; Hogarth 1999).

Mangroves of the Indic Ocean and western coasts of Pacific Ocean harbour more tree and shrub species than mangroves of the Atlantic Ocean and eastern coasts of the Pacific Ocean. This *anomaly in mangrove vegetation* has been explained by

Fig. 1 Mangroves at Bonaire are presently dying off at a large scale, because of the inflow of *Sargassum* algae that decomposes in the salinas (photographed by Joop Schaminée)

different evolutionary histories combined with limited occupation of the stressful marine environment from terrestrial lineages (Jayatissa et al. 2002; Ricklefs et al. 2006).

Natural coastal protection, timber production, fishery, and aquaculture belong to the ecosystem services. More than one third of the mangroves have been destroyed during the last decades by clearing, dams and irrigation, construction of aquaculture, and overharvesting (Hogarth 1999; Jin-Eong 2004). Changes in severity and frequencies of storms increase the pressure on mangroves in Indian ocean and Northern America.

Sargassum brown tides are examples of the global context of coastal ecosystems. Large amounts of *Sargassum* algae wash seasonally ashore on Caribbean islands, creating a thick layer of toxic organic biomass which suffocates the mangrove trees. The brown tides formed mid-Atlantic and are caused by nutrient loads originating from erosion in the Amazon, Orinoco and Congo river (Van Tussenbroek et al. 2017).

3.4 Saltmarshes

The 1960 classic study of Chapman on "salt marshes and salt deserts of the world" already revealed the almost infinite diversity of saltmarshes, referred to as saline areas of land bordering on the sea. In some parts of the world, they carry a highly varied vegetation, whilst in other places only one or two species dominate. Sites covered with vegetation frequently alternate with bare sites, often at close distance to each other. Salt marshes can develop around dune complexes on (barrier) islands, where water dynamics are limited, on the foreland of mainland coasts (often of an anthropogenic origin) or on isolated mainland remnants, so-called Hallig salt marsh islands (Esselink et al. 2017).

Generally, a saltmarsh can be divided into a seaward section (lower saltmarsh), naturally inundated by the tide more frequently, deeper and longer than a higher positioned landward section (upper saltmarsh), but the picture is often more complex. The area under influence of the tidal regime is generally referred to as the intertidal zone (e.g. Esselink et al. 2017). The marshes may be intersected by irregularly twisting creeks, that empty at low tide and fill up again at high tide, showing their own zonation from the creek margins to the lower flats a bit further away. Another important gradient relates to estuaries. When a river reaches the coastal plain, it will come within tidal influences: the barrier effect of the flooding tides reduces the flow of the river water, enhancing the deposit of sediments and as such the development of marshes. The distance to the sea has a direct effect on the salinity of the water, ranging from saline in open sea over brackish to completely fresh further stream upwards in the river.

Other important factors relate to the magnitude of the tides, ranging from more than 16 m to almost zero. The highest tide in the world is found in Canada at the Bay of Fundy, with other extremes at the Atlantic Coasts of Great Britain and France.

Fig. 2 Grazed salt marsh with *Salicornia europaea* (red) and *Tripolium pannonicum* (syn. *Aster tripolium*, pink) on Læsø, Denmark. Because of tectonic uplift the range of saltmarches of this island will still grow despite rising sea level (photographed by C.H.)

This is in sharp contrast to more or less enclosed basins, such as the Baltic Sea (Fig. 2), Black Sea, Caspian Sea and Mediterranean Sea. Here, the differences between high and low tide measure only a few decimetre at the maximum and are to a large extent depending on wind conditions (e.g. Pätsch 2019; Medvedev et al. 2016). Of major influence on the vegetation is also the type of substrate that may range from sandy over silty to clayey and from mineral to peaty.

On global scale, saltmarshes are primarily associated with middle and higher latitude regions, because in the tropics and subtropics their position on the landscape is largely taken by mangroves or other woody vegetation on brackish ground. Here, grassy saltmarshes may develop at places where the mangroves have been cut over, like in Brazil, where *Spartina brasiliensis* may form such grassy patches. Chapman (1960) distinguishes 9 groups of marine saltmarshes along the world, starting with a north European group, ranging from the Iberian Peninsula northwards to southern Scandinavia. The salt marshes of the American and Canadian arctic regions, together with their European and Asian counterparts are treated as a separate group, just like the Mediterranean marshes. Herbs, grasses and algae form the major component in the temperate and arctic communities (with a few bryophytes and lichens occurring at the higher elevated zones), whereas the Mediterranean marshes are mainly characterized by shrubby vegetation. In temperate North America, Chapman distinguishes between a western and an eastern group. On the Pacific coast, the marsh formations are not so extensive as those occurring on the Atlantic Coast. On the southern hemisphere, Chapman recognizes (outside the tropics) a South American Group and an Austro-New Zealand group. On the pacific coast of South America, distinct effects of a climate gradient on the species compositions are shown by Fariña et al. (2017). Here, the salt marshes are divided in arid coastal habitats dominated by *Sarcorcornia fruticosa* as well as temperate habitats in the South with high *Spartina densiflora* abundance. In Australia and New Zealand, salt marshes form extensive habitats sometimes over 10 km wide, but mostly confined to estuarine environments or barrier estuaries. Mangrove encroachment is one of the major threats for salt marshes, mainly in northern Australia (Saintilan et al. 2009).

In many parts of the world, saltmarshes are directly or indirectly influenced by human activities. Moreover, large areas are used for grazing (Fig. 2), hay making or food harvesting. Especially in regions with protected saltmarshes, the question of the intensity and reduction of grazing has intensively been discussed during the last 50 years. Many saltmarshes along the North Sea, for instance, are heavily overgrazed by domestic animals (mainly sheep). Natural grazing takes place by geese and hares. The majority of rather brackish plant communities found along the Baltic Sea coast rely on (very) moderate grazing regimes (Pätsch et al. 2019) in combination with other factors of which elevation is most dominant (Jutila 2001). Where grazing does not take place, succession stages dominated by *Bolboschoenus maritimus*, *Elytrigia repens*, *Phragmites australis* or *Schedonorus arundinaceus*, or even willow shrubland and *Alnus glutinosa* woodland, would be able to replace them. Moderate grazing might facilitate coastal ground-breeding birds that profit from the structure of salt pastures, as has been demonstrated in National Parks of the German Bight (Looijen and Bakker 1987; Kirsch 1990).

3.5 Rocky Shores

Rocky shores are hard transitions from sea to land often accompanied with a steep difference in altitude. Water currents and erosion form strongly accented coastlines, sometime with cliffs rising hundreds of metres above sea level. Also, artificial structures may show similar characteristics as rocky shores. Examples are docks, dikes or even ships and buoys can function as comparable hard substrate for algae and invertebrates.

The lifeforms living on rocks are distributed over several zones depending on their contact with salt sea water and wave action. Brown and red algae, molluscs and crustaceans like barnacles inhabit the sub-, low- and mid-tidal zones, while higher up mussels and periwinkles are attached to the rocks in high tide zones. In the splash zone lichens can start growing (Denny and Gaines 2007). On less inclined areas between the rocks, rock pools can form with stagnant sea water. In these small pools, many species of the lower zones or even marine species can find temporal refuge. The limited size of the rock pools facilitates extreme conditions as salt levels rise due to water evaporation. Higher up on the cliff, on the edges of the rock faces vegetation with salt tolerant plants such as *Armeria maritima* develops. These rock edges are home to sea birds that need to nest in the vicinity of their fishing areas. Sea gulls, Albatrosses and Puffins form colonies that nest together on the same cliffs, sometimes with hundreds of thousands of birds at the same time. On some islands the amount of guano produced by these birds covers entire cliffs and is sometimes mined by local industries as a resource for fertilizer.

Even forests can develop along rocky shores, for example the pine forests in the sheltered bays and fjords in Scandinavia or the cloud forests on the eastern shores of the Azores Archipelago, where Atlantic rainforest reaches the ocean (Elias et al. 2016). In northern California, dense forests of the immense Redwood trees (*Sequoia sempervirens*) also cover the rocky shores of the Pacific coasts. Again, here the system is comparable with a rain forest system but fed by incoming sea mist (Sawyer et al. 2000).

Natural disasters, pollution and the change in sea water temperature can also have a negative influence on the biota of rocky shores. Especially mollusc species are susceptible to pollution. Additionally, exotic, sometimes invasive, species can easily enter coastal rocky ecosystems.

3.6 Dunes

The transition between sea and land can be either very swift and hard, when we talk about rocky shores and cliffs or either very gradual and soft when looking at mud flats and saltmarshes. However, there is also an intermediate system, where sand, water and wind take control: the coastal dunes (e.g. Figs. 3 and 4).

Coastal dunes are aeolian driven ecosystems which are located on the boundary of sea and land where there is a sufficient availability of coarse sandy soils. Therefore, dune ecosystems are azonal distributed across the world. The dynamic processes in dunes are driven by interactions between water, wind and vegetation succession, starting at a beach moving inland via pioneer dunes, white dunes, grey dune grassland and (moist) dune slacks to dune shrublands and forests.

Fig. 3 Dune landscape with white dunes with Marram grass (*Ammophila arenaria*) in the front, to grey dune grasslands, wet dune slacks and forests in the distance (photographed by Nils van Rooijen)

Fig. 4 Dune complex with *Euphorbia paralias* (foreground) of Istmo de la Pared, Fuerteventura, representing one of the oldest and largest, and only moderately affected dune areas of the Canary Islands (photographed by Carsten Hobohm)

Dunes are formed in coastal areas where enough sediments are available, and the sand supply is continuously replenished. Moderate marine currents can supply beaches with sand derived from estuaries or old sediments on the nearby sea floor. For a sufficient sedimentation gradual shores are necessary. Here, water currents are slowed down, sedimentation occurs, and beaches are formed. These shores can stretch for great lengths, for example the kilometres-long beaches in north-western Europe, Brazil and south-eastern Australia or can form small patches in sheltered corners between rocks and cliffs. However, in the latter there is no room for an entire dune system to form. Nonetheless, beaches can harbour some diversity. Many bird species rely on beaches for food or even nesting grounds. In addition, crustaceans, insects and even some amphibians find their habitat on beaches. Plants and fungi form drift line communities on organic matter washed ashore.

The presence of wind is another important variable necessary for dune formation. Wind transports the sediments land inwards and is the main driver for the formation of dune structures and a condition to which the entire ecosystem is adapted.

The general geomorphology of dunes consists of a classification which follows dune succession land inwards. The spatial sequence is called xeroseries. Pioneer dunes are formed when pioneer vegetation catches and collects sand particles transported by wind or water. With a growing pioneer dune more sand, water and organic material is concentrated eventually succeeding into a vegetation with species such as Marram grass (*Ammophila*) which is a dominant genus distributed around the world. As these plants accumulate more sediments, the dunes start growing. The roots of Marram grass can follow the growth of the dunes and their leaves are resistant to sharp blowing sands. This system is called the primary or white dunes, where sand transport is still one of the major driving processes. The dunes grow up to several tens of meters forming a natural dyke between the coast and inland areas. Where sand and wind availability are optimal dunes can grow up to more than 100 m, e.g. along the western French coast or the Namibian coastline. Where less sand is available, the white dune area may reach only 3 m in height, as can be seen along some Mediterranean coasts (Doody 2005). Due to the continuous aeolian activity, white dunes are very dynamic and can move up to several meters year or more during storms (Martínez and Psuty 2004).

On the lee side of the primary dunes, aeolian processes have a less omnipresent impact. Here, the sediments can settle, and vegetation is able to develop. Due to soils poor in nutrients, extremes in temperature and water availability, dune grassland often develops in sediments with a higher lime content. In less calcareous soils heather species become dominant. The prominent presence of mosses and lichens give these grasslands a grey appearance, thus they are also known as ‘grey dunes’. Open sandy spots in the grassland, some caused by the digging of rabbits or larger grazers, are vulnerable for the dominant winds and form blow outs. If the direction of the wind is dominant, blow outs can initiate the formation of parabolic dunes, a very distinct pattern in the landscape. Where parabolic dunes accumulate sediments, the blowouts may be wind excavated down to the ground water level. Here wet dune slacks may form of even small lakes which show a remarkable diverse vegetation (Goudie 2011).

Eventually dune grasslands accumulate organic material in the otherwise rather sandy soil and wind and sand become a less dominant factor. Encroachment with larger grasses and forbs as well as the establishment of shrub species lead up to the dune forests in moderate climates or dense shrublands (e.g. maquis vegetation) in Mediterranean areas. Also, the wet dune slacks accumulate organic matter and eventually form an environment where birch forests can develop.

3.7 Inland Saline Habitats

In former times, inland saline habitats were often seen as badlands, and the landscape scenery was not always perceived as beauty in the eyes of residents. However, especially during the last decade’s scientific publications have pronounced the uniqueness of these habitat types (e.g. Evans and Roekarts 2015, factsheets of the European Environment Agency 2019, and pers. comm. with farmers).

Natural inland saline habitats can occur under arid or semi-arid conditions where evaporation causes increasing salt concentrations, and in regions where saline or alkaline waters flow out of the geological surface (salt springs). Such habitats may also occur where excavation material of mining activities is deposited (Pernik and

Hulisz 2011). Various animal and plant taxa are adapted to high and/or fluctuating salt concentration, little freshwater and desiccation. Vascular plant families which regularly occur in saline flats are e.g. *Chenopodiaceae* (*Salicornia*, *Sarcocornia*, *Suaeda*, *Enchylaena*, *Sclerolaena*, and many others), *Plumbaginaceae* (e.g. *Limonium*), *Poaceae* (*Puccinellia*) and *Aizoaceae* (e.g. *Gunniopsis* in Australia). Many genera represent higher species numbers inland than in coastal saltmarshes.

Salt steppe, brackish swamps or halophytic shrubland, salt lakes and crusts of salt without any vegetation but characteristic fauna can be found in the surrounding of depressions, sources or running saline or brackish waters In many cases the salinity of soils and waters is not stable and may change periodically in relation to the precipitation regime, or increases or decreases over a long time (Williams 1978; Westhus et al. 1997; Luo et al. 2013, 2017).

4 Species Diversity and Threatened Biota

4.1 Diversity

In general, the biodiversity, i.e. number of species or individuals per unit area, and biomass declines when comparing coastal to deep sea regions. However, as the scientific exploration of the deep sea is expensive and the community of ecologists working on deep sea ecology is small, also the knowledge on the deep sea is limited (Tittensor et al. 2010).

The diversity of organisms at higher taxonomic levels is much greater in the seas than on the land. This fact has to do with the high age of oceans and the long evolutionary history (Goetting et al. 1988; Mora et al. 2011).

Taking into account that only a very small proportion of the Earth's surface is covered by coastal habitats, the amount of species and endemism adopted to the this small transition zones is high. In general, tropical regions harbour higher marine, coastal and near-coastal biodiversity and almost the whole range of marine biodiversity hotspots in comparison with higher latitudes (Roberts et al. 2002; Worm et al. 2005; Ramírez et al. 2017).

4.2 Threatened Biota and Threats

Table 2 gives an overview of numbers of threatened species in shallow (subtidal) coastal waters. According to the numbers in this table, the related habitats are highly vulnerable and impacted by humans. Figure 1 gives an example of a recent vegetation dieback at Bonaire.

The Pacific Ocean harbours the largest number of critically endangered (CR) or threatened species (CR, EN, plus VU). The Indian Ocean and Atlantic Ocean are

Table 2 Numbers of threatened species of shallow (subtidal) coastal waters with respect to geography, taxonomy and threat (IUCN 2019; threat categories: *CR* critically endangered, *EN* endangered, *VU* vulnerable; marine neritic categories 9.2–9.9). Note that several species can live in more than one region and may be threatened by a combination of different factors. Thus, not all numbers are additive

	CR	CR, EN, VU
In total (globally)	92	756
Arctic Ocean	0	1
Atlantic Ocean	27	201
Mediterranean and Black Sea	11	40
Indian Ocean	31	359
Pacific Ocean	40	473
Tracheophyta (vascular plants)	0	11
Rhodophyta (red algae)	5	6
Actinopterygii (ray-fin fishes)	21	258
Aves (birds)	14	28
Reptilia (reptiles)	3	12
Mammalia (mammals)	0	10
Chondrichthyes (cartilaginous fishes)	33	122
Myxini (hagfishes)	1	6
Sarcopterygii (lobe-fin fishes)	1	2
Arthropoda (arthropods)	0	3
Mollusca (mollusks)	4	42
Cnidaria (coelenterates)	7	236
Echinodermata (echinoderms)	0	15
Threatened by residential and commercial development	25	360
Threatened by agriculture and aquaculture	4	27
Threatened by energy production and mining	6	32
Threatened by transportation and service corridors	11	265
Threatened by biological resource use	73	586
Threatened by human intrusions and disturbance	13	280
Threatened by system modifications	10	46
Threatened by invasive and other problematic species, genes and diseases	32	313
Threatened by pollution	25	392
Threatened by geological events	1	3
Threatened by climate change and severe weather	37	398

taking position number two and three and the Mediterranean and Black Sea together number four.

Fishes, birds, coelenterates, red algae, molluscs, reptiles and mammals all harbour taxonomic groups with high numbers of critically endangered species. For both groups of Red List categories, critically endangered and threatened species, the most important threats are biological resource use, climate change and severe weather, pollution, residential and commercial development, and invasive and other problematic species, genes and diseases.

Table 3 Numbers of threatened species (IUCN 2019) of intertidal, coastal supratidal and inland saline habitats with respect to habitats (categories 1.7, 5.14–5.17, 12, 13), geography, taxonomy and threats (threat categories: CR = critically endangered, EN = endangered, VU = vulnerable, habitats 1.7, 12, 13). Note that several species can live in more than one region and may be threatened by a combination of different factors. Thus, not all numbers are additive

	CR	CR, EN, VU
Number of threatened species	191	1043
Intertidal rocks, sands, mud flats, tidepools and seagrass beds, coastal saltmarshes and halophytic shrubland	41	269
Mangroves (intertidal and above high tide level)	45	276
Marine coastal/supratidal lagoons, cliffs, dunes, and dune slacks	111	567
Inland saline, brackish or alkaline wetlands	22	113
North America incl. Greenland and excl. Hawaiian Islands	4	56
Mesoamerica and Carribean Islands	41	210
South America	11	132
Europe	43	183
Africa	43	292
North, West and Central Asia	11	109
East, South and Southeast Asia	32	230
Antarctic	1	16
Tracheophyta (vascular plants)	73	307
Bryophytes	0	0
Rhodophyta (red algae)	1	2
Actinopterygii and Chondrichthyes (fish species)	18	176
Aves (birds)	25	213
Reptilia (reptiles)	24	116
Amphibia (amphibians)	2	6
Mammalia (mammals)	8	121
Mollusca (mollusks)	7	27
Threatened by residential and commercial development	80	511
Threatened by agriculture and aquaculture	60	419
Threatened by energy production and mining	23	152
Threatened by transportation and service corridors	23	133
Threatened by biological resource use	76	519
Threatened by human intrusions and disturbance	33	221
Threatened by system modifications	40	260
Threatened by invasive and other problematic species, genes and diseases	88	403
Threatened by pollution	35	285
Threatened by geological events	9	41
Threatened by climate change and severe weather	55	320

Table 3 gives an overview of numbers of globally threatened species which live in or depend on intertidal, supratidal and inland saline habitats. According to the IUCN Red List (2019) most critically endangered (CR) or threatened (CR, EN, plus VU) species of coastal and inland saline habitats belong to a few taxonomic groups: vascular plant, reptile, fish (Actinopterygii and Chondrichthyes), bird and mollusc species (most of the latter are sea snails and slugs). Coastal supratidal habitats harbour more threatened species than intertidal or inland saline habitats (cf. also Table 2).

Europe, Africa, Mesoamerica and the Caribbean Islands represent high numbers of critically endangered and/or threatened species of the related habitats; North America, South America and the Antarctic represent smaller numbers.

5 Examples of Restoration Projects

Restoration measures can be related to both ecological and societal goals. Societal goals comprise fishery, energy production, shoreline protection, tourism, the scenery and beauty of the landscape, and are linked with human survival and health, and economic benefits. Ecological goals for example, aim at the conservation or re-establishment of native biodiversity, reduction of threats to the biota, and/or zero-use and wilderness. These goals may be discussed at different spatial scales from local to global. Nature conservation measures can easily be applied if these also follow social goals and financial investments are manageable. It is, however, more tricky to look for solutions in complicated situations with competing interests of invasive humans, invasive biota, and natural biodiversity (Schuster and Doerr 2015). The lack of public awareness of losses of less charismatic ecosystems results in the continuation of detrimental practices and therefore contributes to continued declines of coastal ecosystems. More effective communication of scientific knowledge about these uncharismatic but ecologically important coastal habitats is required (Duarte et al. 2008).

The following examples partially face promising projects with respect to habitat restoration and species conservation.

5.1 Restoration Projects on Coral Reefs

Coral reefs and mangroves are often linked to each other with regard to their functioning in the landscape, whereas both are important system engineers. Various projects, for example at the coasts of Florida, Caribbean Islands, Australia, Thailand, and Egypt, are working in restoration of coral reefs. These include research and monitoring, genetic analyses, coral gene banking efforts, cultivation and reproduction of corals and other species, ecological engineering, species reintroduction into natural habitats, and education. Especially the development of coral nurseries and cultivation of endangered coral species such as *Acropora* species seem to prove successful efforts (Precht 2006; Yeemin et al. 2006; Rinkevich 2008; Ammar 2009; Sen and Yousif 2016; O'Donnell et al. 2018).

5.2 *Restoration of Mangroves*

Mangrove forest restoration often focuses on restoring the environmental conditions as planting of mangrove tree species often fails. Combining planting with increasing the water quality by measurements elsewhere (e.g. erosion prevention in river delta's or limiting nearby aquaculture) has more effect. The best practise to restore mangrove systems, however, is to create entirely new habitats. This is very costly and hard to achieve over large areas, but as the necessity for resilient and durable coastal protection grows, mangroves restoration may present a good option for the long-term (Lewis III et al. 2005).

5.3 *Restoration Projects of Saltmarshes and Tidal Flats*

The Wadden Sea at the coasts of the Netherlands, Germany and Denmark is the largest tidal flat system in the world. These three countries therefore have an important international responsibility to protect these habitats. A large part of this area belongs to national parks and most habitat types are additionally protected by the European Habitats Directive and additional (national) regulations. However, despite regulations and measures for nature protection the Wadden Sea is highly impacted by waste, pollution and eutrophication, dumping of dredge spoil, shipping, fishery, residential and commercial development, energy production (oil and gas extraction, wind parks), coastal defence measures, tourism, and diverse other anthropogenic influences (e.g. Tougaard and Ovesen 1981; Goetting et al. 1988; Hobohm 1992, 1993; Lasserre 1994; Hughes and Paramor 2004; Kirwan and Megonigal 2013; Gu et al. 2018). Many pollutants and debris wash ashore after it has been lost by ships. For example, in 2019, the cargo vessel MSC Zoe lost over 200 transport containers in the North Sea near the German coast. Within days, the beaches of the Wadden isles were covered with chemicals, micro plastics and plastic pallets which are likely to enter the food web of the dunes. Additionally, on the long-term land subsidence, insufficient sediment supply and the rising sea level may impact parts of the Wadden Sea (Baptist et al. 2019).

For the Wadden Sea saltmarshes, the following five targets have been formulated in the trilateral Wadden Sea plan of The Netherlands, Germany and Denmark (Esselink et al. 2017):

1. maintaining the full range of variety of saltmarshes typical for the Wadden Sea landscape;
2. achieving an increased area of saltmarshes with natural dynamics;
3. achieving an increased natural morphology and dynamics, including natural drainage of mainland saltmarshes, under the condition that the present surface area is not reduced;
4. maintaining a saltmarsh vegetation diversity reflecting the geomorphological conditions of the habitat with variation in vegetation structure;

5. maintaining or to achieve favourable conditions for all typical species.

Restoration projects comprise e.g. the recovery of Eel Grass (*Zostera marina*) and mussel beds (*Mytilus edulis* and *Ostrea edulis*), and ecological restoration of saltmarshes include de-embankment of summer polders and re-develop former geomorphology and drainage systems. Restoration the widespread occurrence of *Zostera marina* in the Netherlands is a real challenge, as the population at all locations of restoration substantially decreased due to reduced seed production (van Duren et al. 2013, 2014). Most likely, the water conditions, i.e. chemistry and/or light are not adequate. Moreover, a fungus is threatening eel grasses. The establishment of mussel beds (de Paoli et al. 2015) is a challenge too. Currently, the possibility of using bio-degradable artificial reefs for mussel bank settlement is studied in the Wadden Sea area. In contrary, restoration measures in saltmarshes face higher success (Bernhardt and Koch 2003; Esselink et al. 2017). Salt marsh restoration by habitat increase can be achieved via e.g. large scale de-embankment (Wolters 2006). However, it can be assumed that restoration projects might become more successful if major impacts, i.e. artificial limitation of natural dynamics, the amount of nutrients and pollutants, will be reduced on regional or even global scale in the future.

5.4 Restoration Projects of Coastal Dunes

Active dunes and wet dune slacks in general represent areas of positive sedimentation rates. Under natural conditions unvegetated dunes are migrating due to erosion at one side and sedimentation at the other. Later succession stages of dunes show more or less dense vegetation cover, i.e. pioneer vegetation, vegetation dominated by grasses and herbs, dune shrubs, and finally forest if the airborne content of salt is low enough.

Lithgow et al. (2013) defined and assessed variables influencing the success of restoration measures in dune areas. They used different criteria and subcriteria such as degree of degradation, system fragmentation, stress factors, factors that facilitate restoration, and 38 indicators such as visitor pressure, infrastructure affecting sediment dynamics, and so on.

Restoration of coastal dunes and beaches including wet dune slacks has many goals, facets, and mechanisms. Correspondently, the natural heterogeneity of dune systems and the special conditions including human influences of each site needs to be assessed. Numerous restoration projects showed that anthropogenic influences cannot completely be compensated with respect to natural conditions including hydrology, biodiversity and aeolian transport of sand, for example. Thus, also the re-introduction of traditional management technics such as mowing, grazing, sod removal and non-traditional construction of artificial habitats such as wet dune slacks might be tested and evaluated (Grootjans et al. 2002).

However, one comprising target is the re-establishment of the natural dynamic. Thus, national and regional authorities should give space to natural dynamics and free movement of dunes in coastal areas as much as possible.

The dynamic nature of dunes (Figs. 3 and 4) was, and sometimes still is, considered as a challenge. Through history, human settlements near coastal dunes were threatened by the moving sands. There are many examples of villages which even disappeared underneath the sands. Examples of lost villages are Sier on the wadden isle of Ameland, Berkheide near The Hague, a town called Onze Lieve Vrouwe op Zee on Duiveland, Kenfig in Wales and Shoyna in Russia (Williams and Davies 2001; Stulp 2011; Raffaele and Bruno 2019). As we have seen before, people tried to decrease the dynamics of the sand by fixing the dunes through the plantation of either Marram grass (and other sand-binding grasses) and pine trees. However, by reducing the natural dynamics, the functioning of the ecosystem is affected. Vegetation succession and encroachment of shrubs and trees are accelerated, whereas invasive species may enter and degrade the system. Species such as Japanese rose (*Rosa rugosa*) in temperate coastal regions of Europe or Sour fig (*Carpobrotus edulis*) in many warm coastal regions worldwide are often concentrated in areas with limited natural dynamics. At the Baltic and North Sea coasts, the Japanese rose is often removed mechanically because the species richness is lower in plots where this species occurs (Isermann 2008; Novoa et al. 2013).

In the past, at North and Baltic Sea coasts, rabbits were—at a large scale—able to keep the dune landscape open, through grazing and the digging of holes, but there populations have been decimated by (sometimes deliberately introduced) viruses, like VHS and Myxomatosis. Nowadays, intensive management is often necessary to maintain an open dune landscape. One common practice is the introduction of large grazers into the dunes, but their effect is often insufficient. Cattle and horses are often not able to keep up with the encroachment of woody plants. In some cases, they even increase encroachment by concentrating nutrients and compacting the soil, preventing aeolian processes resetting the system. Meanwhile, nitrogen deposits from heavy industries, often located near harbours, increase the rate of encroachment. One specific victim of human influence in the dune system is the Northern wheatear (*Oenanthe oenanthe*), a passerine bird that nests in abandoned rabbit holes in dune grasslands. As the vegetation closes, the small ground orientated bird loses habitat and nesting opportunities. Moreover, heavy metal industries and nearby marine transports are causing an increased deposition of toxins in dune areas. Dioxin levels in the eggs of the Norther wheatears in the Dutch dune system are that high that a large amount of the embryos die before hatching (Van Oosten 2015).

Sand dunes of shorelines are natural defence systems against forces of the sea. However, in many regions the dynamic of coastal dunes is part of the controversy between nature and coastal protection. For example, dunes in the Wadden Sea area to a great extent are artificially stabilized by plantations of *Ammophila arenaria* or *Ammocalamogrostis x baltica*, also in areas where the sedimentation rate is positive. In contrary to natural unvegetated and vegetated dunes such plantations are species-poor, and normally do not offer space for rare, endemic or threatened species. Fences are used across all dune areas in Europe to control the stream of visitors, with the effect that no plants can grow where the visitor impact on sandy ground is high. On the other side, behind the fence dense and often shrubby vegetation occurs. The natural sequence of succession stages cannot be observed under such circumstances. In some dune areas, it is a successful policy to tolerate trespassing fences.

Recent approaches along European dune systems focus on returning the natural dynamics and homogeneity in the landscape (Grootjans et al. 2002; Provoost et al. 2011). Artificial blow outs are created, or even entire dunes are removed to open up the coast line. In some cases, on islands, the opening of dunes facilitates wash-overs to occur, sea water flowing through the dunes into the saltmarshes on the other side of the dune system, increasing a potential for nature. Where sand was once fixed, it is now mobile and can reach weaker dune complexes through natural processes, increasing the overall resilience of the dunes. Artificial blow-outs may provide new sources of sand to rejuvenate coastal grasslands and provide space for flora and fauna that need open areas (Aggenbach et al. 2018). In suitable areas, new dunes or new sand flats are being created on the coastline, sometime referred to as sand engines. In other cases, sand is added to the beach. This so-called sand suppletion functions as a source of sand for natural dune areas and provide new space for beach communities.

Although many coastal dune restoration projects have been evaluated as successful with respect to target species, target communities, elimination of anthropogenic residues and elimination of exotic species or woody plants (e.g. Petersen 1999; Grootjans et al. 2002; Ruz et al. 2005; Nygaard et al. 2011; Martínez et al. 2013; Lithgow et al. 2013; Eischeid et al. 2018), it is still unclear and debatable how effective the various measurements in dune systems at the long term might be. This could apply to the introduction of large grazers and the creation of blowouts. It is quite possible that the re-introduction of extensive traditional management techniques, such as mowing, grazing, sod removal and rewetting dune slacks, will be necessary in the long term (Grootjans et al. 2002). The difficulty lies in the elemental drivers of the dune system: water and wind. These drivers seem to be part of a much larger system subject to climate variables and weather conditions. There are indications of large cyclic events that affect atmospheric and oceanic currents (for instance El Niño, or the North Atlantic Oscillation), having an effect on local and regional aeolian processes in dune systems. Artificial measurements that intend to restore the fundamental dynamics of dunes should take the complex interactions in consideration (González-Villanueva et al. 2013; Van Rooijen et al. 2018).

5.5 Restoration Projects of Rocky Shores

Rocky shores are generally no subject for habitat restoration, as they simply perform just as they are, as long as their existence is guaranteed. An interesting item, however, with respect to the 'restoration' of rocky shores and their species, is the construction of artificial structures, which may facilitate a high biodiversity. As an example, a remarkable project is that of the Afsluitdijk in the north of the

Netherlands. The Afsluitdijk is a dam created to protect the low-lying county from flooding. By establishing the dam in 1932, the Zuiderzee bay was cut off from the North Sea and Wadden Sea creating the fresh water lake IJsselmeer. The dam was constructed of basalt stone on the Wadden Sea side. After 80 years, remarkable plant species established on this artificial rocky slope, like Wild Cabbage (*Brassica oleracea var. oleracea*), Sea Kale (*Crambe maritima*) and Sea Beet (*Beta vulgaris subsp. maritima*), species that are rare in this area. Wild Cabbage is endemic to coastal regions of western Europe and only a limited number wild populations are known (Gustafsson and Lannér-Herrera 1997). As the Afsluitdijk needs to be renovated to current standards for coastal protection, the entire dam is being renovated. Therefore, the basalt will be replaced by concrete, and the entire vegetation cover will be removed. To protect the various plant species, the seeds are collected before building starts to ensure the preservation of the plant genetic diversity. The new concrete substrate is designed in such a way that it is fitted with small cracks and spaces for the establishment of vegetation (and coastal fauna). The seeds (or carefully bred offspring) will then be reintroduced on the renovated habitat.

5.6 Restoration Projects of Inland Saline Habitats

The ecological meaning and environmental conditions of salt lakes, inland salt steppe, and continental alkali marshes including brackish reeds and halophytic shrubland has been studied, mapped and assessed in many countries and regions. In general, the uniqueness including endemic, rare and threatened plant and animal species has often been proved during the last years or decades. According to Flora Iberica (Castroviejo et al. 1993), for example different *Limonium* species such as *L. album*, *L. aragonense*, *L. dichotomum, L. erectum*, *L. hibericum*, *L. longebracteatum*, *L. paui*, *L. ruizii*, *L. soboliferum*, *L. squarrosum*, *L. stenophyllum*, *L. toletanum*, *L. viciosoi*, and some more are Iberian endemics which are confined to inland saline or alkaline depressions and borders of lakes (Castroviejo et al. 1993). However, also critically endangered species such as Sociable Lapwing (*Vanellus gregarius*) which has a relatively large range across Northern Eurasia, Northeast Africa and India depend on or profit from the existence of inland saline habitats. However, the breeding ground of this bird is much smaller than the range of occurrence (IUCN 2019).

Moderate grazing, in some cases also mowing, removal of sod, and/or limitation of strong visitor impact are identified as adequate instruments of nature conservation policies. However, in many cases it is useful and cost-efficient to simply keep the habitats untouched (e.g. Allen et al. 1997, Pardo et al. 2003, Ministerium für Landwirtschaft, Naturschutz und Umwelt Thüringen 2005, Šefferová et al. 2008, Balázs et al. 2014, Janssen et al. 2016 incl. fact sheet E 6.1 on Mediterranean inland salt steppe).

6 Challenges and Future Perspectives in the Light of Land Use and Climate Change

Reliable planning of future potential nature-based protection of coastal habitats depends on ideally precise scientific models of expected relative sea-level rise at regional to global scales, a good knowledge on the geomorphology of the landscape, a broad understanding of the dynamics and ecology of coastal habitats and their major threats in the region, the availability of reliable socio-economic data, and a further development of improved models integrating these major components to calculate best possible future scenarios. Regarding the implementation of scientific results, Spalding et al. (2014) additionally highlight the need of tools and decision support systems helping communities to understand coastal hazards in their region and finding nature-based solutions for future protection of the coast. Provided that research-driven, nature-based development of strategies for coastal protection is given, we assume that for many communities which are exposed to flood risk or other problematic factors, one can obtain a decreased vulnerability.

The climate changed dramatically during the last 30,000 years and the global sea-level arose by 120–140 m since last glacial maximum. Thus, coastal habitats had to migrate vertically and horizontally—on occasion up to hundreds of kilometres—in relation to the shifting climate zones (Ray and Adams 2001). Likewise in recent times, the coastal systems are subdue to many factors, making it hard to forecast the available area for coastal habits in the future. Geomorphological aspects such as horizontal and vertical movements of the earth' crust) also reflect parts of the current ongoing change of coastal landscapes. This includes the regional land-upheaval caused by glacial rebound, which for instance can be observed in Scandinavia (Hill and Wallström 2008). Opposite in character is coastal subsidence, as can be seen in certain delta areas such as the Huanghe Delta, New Orleans. Some of the towns, cities and habitats at the coast are sinking faster than the sea level is rising. Subsidence drivers are both natural and anthropogenic processes (Meckel et al. 2006; Syvitski et al. 2009; Strozzi et al. 2013; Auerbach et al. 2015).

Such geological processes, also including erosion and sedimentation, and human activities such as the creation of artificial islands caused an increase in coastal area of 13600 km^2 between 1985 and 2015 (Donchyts et al. 2016). However, the increased area of coastal land does not, in any means, guarantee the quality and quantity of natural coastal habitats in the future.

Different processes and land use change will have different effects to humans and biodiversity. Although climate-related extremes such as floods and hurricanes imply a much higher risk for humans and human buildings at the coast than for natural habitats, which evolved under dynamic conditions and are adopted to strong coastal wind and water dynamics (Nishida et al. 2017), natural resilience of coastal habitats is now often impaired by anthropogenic factors, and climate extremes have become a growing threat to these systems.

Combined factors of massive land-use and climate change add new challenges to the future of coastal landscapes and may ultimately result in small and rather isolated strips of coastal vegetation lacking fully functionality. Current land-use change adversely affects quality and quantity of coastal habitats through pollution, reduced sediment availability, suppressed natural dynamics, among others. These may ultimately result in just small and rather isolated strips of still well-functioning habitats. These negative changes are connected to a strong intensification of industry and a rapidly increasing building development (settlements, tourism, coastal defence). Moreover, regional and global shifts in climatic conditions and relative sea-level rise, although difficult to predict, may strengthen the effects of other human impacts.

Consequently, the natural dynamic and the capacity of coastal habitats to migrate inland and to build up vertically is reduced. At regional level, serious damages have been recorded already for coastal habitats in shallow waters. Regarding small islands, atolls and other vulnerable places, solutions are required. Thus, we are in urgent need to think about and act with long-term, resilient and cost-efficient protection measures.

Conventional coastal engineering is getting increasingly costly due to the need of adjusting the rigid constructions to prevent the growing risk of flooding. It additionally facilitates land subsidence and adversely effects sediment availability owed to the disruption of natural coastal dynamics (Temmerman et al. 2013). Sediment availability is further reduced by sediment compaction from the removal of oil, gas, salt and water from underlying sediments (Syvitski et al. 2009). We therefore need to focus on and implement nature-based solutions. Already now, well-functioning coastal habitats, such as mangroves, saltmarshes, seagrass beds and coral reefs, contribute to the protection of our coastlines across all biogeographical regions of the world. And so, their capacity to attenuate flood waves and storm surges, to decrease erosion, to accumulate sediments (e.g. Spalding et al. 2014) and thus, their capability to grow vertically in relation to sea-level rise (Kirwan and Megonigal 2013) makes them a serious alternative or addition to artificial coastal defence. Studies investigating the capacity of intertidal habitats to function as coastal protection show promising concepts and encouraging results. Still, we need to understand more about the response of coastal habitats to sea-level rise and increasingly unpredictable flooding events on regional as well as on global scales. For example, judging the extent of coastal habitats attenuating storm surges differs between studies (Fonseca and Cahalan 1992; Mcivor et al. 2012; Möller et al. 1999), because of its dependence on frictional effects, wind speed and duration (Resio and Westerink 2008). Restrictions in coastal protection are given in relation to large-scale erosion and enormous tsunami waves (Gedan et al. 2011).

To enable nature-based coastal protection, the conservation and restoration of coastal habitats aiming to build a natural, interconnected and fully functional coastal landscape is required. The functionality of coastal habitats relies on an unhindered spatial and temporal dynamic, which includes horizontal movements, suitable sediment availability (enabling vertical accretion) and a complete species pool. For example, the functional breakdown of coastal habitats owing to sea-level rise may be related to the constraints in horizontal migration of habitats and its successional stages (called coastal squeeze; Feagin et al. 2005), due to the natural geomorphology of the landscape or by socio-economic barriers. Reducing these barriers where possible, may contribute to the enlargement of coastal habitats (e.g. Schuerch et al. 2018).

Additionally, due to building development and artificial coastal defence, the natural dynamic and the capacity of coastal habitats to migrate inland and to build up vertically is reduced. Also, the ecological processes and dynamics of coastal habitats are highly entangled (Duarte et al. 2008; Barbier et al. 2011) and their sound ecosystem functioning partially depends on their positive synergetic relationships (Barbier et al. 2011). For giving an example, offshore seagrass beds and reefs facilitate the sediment availability of nearby saltmarshes or mangroves, which in turn decrease sea-water pollution by functioning as filter for polluted river- or groundwater.

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Wetlands: Challenges and Possibilities

Martin Lindner and Carsten Hobohm

Abstract This contribution deals with recent challenges and prospective developments of mires, bogs, fens and swamps, and of standing and running waters. We ask the question how it might be possible to reduce the anthropogenic pressure to relating habitats and characteristic biodiversity in a long-term perspective.

The most important threats for wetland habitats are pollution, e.g. by use of pesticides, waste of nutrients, metal, and pharmaceuticals, natural system modification, i.e. modification of flow and geomorphology by settlements, establishment of industries, drainings, building of dams, barrages and hydroelectric power stations, biological resource use, e.g. fishery and hunting, invasive and other problematic species, genes and diseases, and the influence of aquaculture and agriculture, partially over long distance.

Various solutions for the management of wetlands with respect to environmental conditions and natural processes have been published and are currently applied. These are e.g. dismantling of dams or disclaimer of new dams and barrages, regulation of water withdrawal for human use, incentives for the reduction of the use of pesticides, fertilizers and other groups of chemicals, establishment of buffer zones, enlargement and establishment of new nature reserves, and many more. However, the influence of moderate use of relating habitats e.g. by domestic grazing or removal of trees should be monitored with a focus on the hydrologic conditions and species conservation of endemic, rare and threatened biota.

We hypothesize that the effectiveness of restoration and protection measures might seriously increase if the focus is widened and especially border and transition zones between agricultural land, industrial area or settlement and wetland are included in monitoring and nature conservation programmes.

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The reduction of a short-term profit at local scales caused by regulations can result in increasing long-term profit at larger spatial scales because self-regulated biodiversity and food webs may lead to higher output of ecosystem services, e.g. products of fishing.

Keywords Mires · Bogs · Fens · Swamps · Running waters · Still waters · Threats

1 Introduction

Because of the outstanding meaning of water for health, food production, industry and technical processes, traffic, transportation including elimination of waste the use and quality of the water is a central theme of the earliest recorded forms of environmental laws (Dellapenna and Gupta 2013). Past and present regulations are related to the fair distribution, use and control of water quality. With respect to benefits on the one hand and to the number of killed and harmed people on the other water is by far the most important environmental factor (Wisner et al. 2004; Moss 2008; Ziegler and Groenfeld 2017).

During recent years, the discussion about carbon dioxide as greenhouse gas and climate change increased. The role of the storage of carbon dioxide in wetlands, especially in the peat of bogs and mires, is discussed in the last 20 years, together with a warning to drain or convert more peatlands into farmland, as they do not only emit carbon dioxide but also methane and nitrous oxide (e.g. Höper 2007; Kayranli et al. 2010). Covering only 3% of the world's terrestrial landscapes, wetlands store more carbon than forests, which cover more than 30% of the surface (Dixon et al. 1994; Joosten et al. 2012). However, drained and damaged wetlands emit 6% of the climate active gases, and this c. a quarter of all land emissions (Joosten et al. 2012).

In the last years the discussion on the economic aspects of biodiversity, including all types of habitats and also the wetlands, found an interesting focus on ecosystem services. The various aspects of ecological, environmental, societal and economic value of wetlands worldwide are described by Maltby and Acreman (2011). These include water retention also for drinking water use, for irrigation in dry areas and for flood control, as well as providing habitats for different species, also species for agricultural use, such as water buffalos. In Germany the discussion lead to calculation of financial value (Ökosystemdienstleistungen, Grunewald and Bastian 2012). Due to the authors, the value of a square meter of bogs and similar habitats in Europe ranges about 200 €.

However, despite the meaning of water for humans and despite an inherent economic value of wetlands the relating habitats are impacted and destroyed like other habitat types. How is this possible? One explanation for the obvious contradiction between the meaning of water for humans and the ignorance towards water habitats might be the fact that the mean residence time of water in the atmosphere is extremely short (9 days) so that the purity of rainwater almost everywhere on earth is high. The marine environment covers 71% of the Earth's surface while wetlands only take 1% (c. 3% of the terrestrial area). Thus, the water cycle including evapotranspiration and precipitation does not depend much on the existence of wetlands and the kind of use and damage by humans.

Nevertheless, because life including humans depends not only on rainfall and because of various economic reasons wetland habitats are also important for humans. Furthermore, in combination with other habitat types such as forest or grassland wetlands and coastal regions are extremely important for the scenery and beauty of the landscape, for tourism and recreation (Bundesamt für Naturschutz 1997).

Wetlands are very important as habitats for biodiversity. Many bird species, almost 40% of all fish species and the majority of amphibians live in wetlands or depend on wetlands. Furthermore, many other taxonomic groups, for example reptile, mammal, mollusk and insect families evolved in or in connection with mires and freshwater habitats (Groombridge and Jenkins 2002).

According to the IUCN Red List (2019) forests harbour the largest amount of critically endangered species (c. 2900) and wetland habitats represent the second largest number (>1500) even if the area covered by wetlands—depending on definitions and habitat types included—is eight to ten times smaller than the area covered by forest.

These numbers underline the meaning of both forest and wetland habitats for the biodiversity on Earth and the meaning of successful conservation programmes and activities in the future.

The term *wetlands* in general comprises mires, bogs, fens, swamps, and freshwater ecosystems such as rivers and lakes including subterranean freshwater systems.

Freshwater ecosystems are lakes and ponds (lentic ecosystems, still waters) and running waters (lotic ecosystems, flowing waters).

With this contribution we review the meaning of wetland habitats for the biodiversity, focus on threatened biota and habitat types, and highlight the meaning of prospective activities to reduce the pressure on relating habitats at large spatial scales and in a long-term perspective.

2 Water Laws and Regulations on Wetlands

Dellapenna and Gupta (2013) presented an overview of laws related to the use of water through 4000 years. They pronounce the global meaning of water laws from the ancient world until today. In the case of large rivers, potential conflicts and national sovereignty are related to supranational or bilateral regulations. Such laws in return have implications on the local control and management of the quantity and quality of the water flow.

Since the establishment of the Ramsar convention, signed in 1971 in the Iranian city of Ramsar and initiated by the United Nations and meanwhile ratified by 170 states, the immense value of wetlands for the existence of diverse species is known worldwide. This does not mean that wetlands are well protected. The Ramsar committee reported a loss of 87% of relating habitats since 1700 and a human interference on 81% of the inland species by human activities only in the last 50 years.

The major effects of wetlands were seen not only in the protection of rare species among birds, but also for other species, as retention areas for water, as carbon storage, as filters, as home for many specialized cultures and also as sites for tourism (The Global Wetland Outlook 2018).

However, enforced by this international attention most countries created legal and administrational guidelines to protect wetlands. These lead not only to protection of the remaining wetland ecosystems, but also to restoration of such systems which were affected by human activities in the past. These were, e.g., the drainage of wetlands and mires for gaining farmland or for exploiting peat, the side-effect of regulation of watercourses in form of faster water runoff, the diking of rivers, but also the side-effects of intensifying of farming by the use of fertilizers and pesticides. The reduction of such influence would be a major step into a more or less sustainable protection of wetlands.

The international working councils of the Ramsar bureau lists 2.372 sites of wetlands covering nearly 253 Mio hectares in 160 states which are protected (Ramsar Sites Information Service 2019). These contain not only mires, but also coastal areas, open waters, rivers etc.). However, this fact does not mean that all Ramsar sites are adequately protected, since conservation in a long-term perspective needs concrete restrictions and measures. The institutionalization of these protection initiatives was strong and profound in many countries, however, more endeavors are needed.

In Europe two prominent regulations are related to the survival and species composition of wetland habitats, the *Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora* (Habitats Directive) and the *Water Framework Directive (2000/60/EC)*

The Habitats Directive was supported by an Interpretation Manual, latest version in 2013 (EU 2013). Several European countries since the beginning of the project worked on the characterization of habitat types and measures in bogs, fens and other wetlands with detailed information about species, communities and other specifications on protected areas

As both regulations focus on the *good ecological* and *chemical status*, all kinds of anthopogenic influence are matter of monitoring and restoration programmes.

3 Mires, Bogs, Fens and Swamps

Mires, bogs, fens and swamps are ecosystems often located between surface water bodies and solid, mineral land accumulating organic matter at the soil surface or water.

The typical vegetation of bogs is composed by bryophytes, small Cyperaceae and dwarf shrubs. The water level is high and a high amount of organic material is stored in the ground. This material can be accumulated under water if oxygen is absent so that microorganisms cannot mineralize the litter from plants. Specialized bryophytes such as *Spagnum* spp. are able to rise the level of wetlands above groundwater, and create elevated bogs. These very specialized ecosystems normally relay only on the input of rainfall. Exceptionally, bogs can occur on mineral soils in regions with extremely nutrient-poor groundwater. The organic layer is called peat, and peat can accumulate to vertical dimensions of several meters.

Due to the requirement of nutrient-poor water bogs are limited to areas with high rainfall or low evaporation (oligotrophic-mesotrophic conditions). In the northern hemisphere the boreal region, and in coastal areas e.g. of the British Isles bogs are widespread. In high mountain zones with high precipitation rates and nutrient-poor soils bogs are common as well.

If the surface of accumulation of organic material is at the level of (mineral) groundwater, the system is called fen or swamp. Fens occur in different climate zones and all areas with a high groundwater level, e.g. along rivers, in coastal areas with high waterlevel (e.g. in the Netherlands) or in basins with limited water runoff. The nutrient content of the water in the soil is normally a little bit higher than in bogs (often mesotrophic). In eutrophic environments the characteristic assemblages can be maintained by regular reduction of above-ground biomass via grazing or moving. Fens are normally more productive than bogs, and vascular plants such as herbs, Cyperaceae and Poaceae are dominant.

Swamps often occur in the same areas as mires. Swamps can exist on mineral and organic soil. Tall grasses, i.e. Cyperaceae and Poaceae, but also members of other monocot families with a reed-habit are often dominant. Some swamps can be ephemeral, so they exist only in some season of the year according to the precipitation or to floods in rivervalleys. Soils under swamp can often be characterized as mesotrophic-eutrophic.

3.1 Current Trends

The distribution and survival of wetland habitats depends on climate and can be altered due to climate change. It can recently be observed that the precipitation rate in certain areas increases while other areas are getting more and more dry (e.g. Lindsay 2016). Thus, some wetlands will disappear, others might appear. Due to specific modes of dispersal this trend might threaten certain characteristic species.

Enforced by the Ramsar convention, but also by several calls from researchers all over the world, two trends are currently seen: the enforcement of protection and the restoration of wetlands.

3.1.1 Protection of Mires

To implement measures in Europe, in many countries special institutions for nature protection got additional competence by employing wetland experts. Thus, the institutionalization of scientific results was much more profound and could be adjusted to local situations. In federal states, e.g. Germany, these institutions work on different spatial scales. The collaboration on these levels is often combined with international cooperation, especially in wetland ecosystems which overlay borders, as well in topics on international importance, like river systems, migrating birds or others. One example for an international collaboration is the protection of a bog at the Danish/German Border, the Froeslev-Jardelunder Bog (European Commission 2004).

Another important development is the establishment of buffer zones around wetlands. These buffer zones are designed to keep fertilizers, use of pesticides on agricultural land, fires and in case of protected animals also visitors out of the core areas of mires and swamps. First inspired by the need to save drinking water resources, buffer zones are now established around other wetlands as well. They are meanwhile not only important for the protection of core wetlands, but play an important role as habitats for other species in the transition zones, e.g. amphibians and reptiles (Semlitsch and Bodie 2003).

3.1.2 Restoration of Mires

For the restoration of mires basic methods are used: Management of the hydrologic system, utilisation of wetlands, and restoring of characteristic vegetation types (Fig. 1).

Management of the Hydrologic System

Mires, bogs and fens are embedded in a larger hydrological system, including water in- and out-flux, precipitation, water retention, evaporation and agricultural use. Depending on the region, some of these factors are more important than others. E.g. precipitation rates of mires in the boreal region are often smaller than in temperate Northwestern and Western Europe. However, because of lower rates of evapotranspiration they can exist there in large dimensions. In semi-arid regions mires depend more on the groundwater system, e.g. in South Africa (Grundling 2014) or in the Mediterranean (Rapetti et al. 1986; Tomei 1982). In these regions, a constant flux of water results in permanent wet top-soils also during dry seasons.

For example, in the case of Lago Massaciuccoli in Italy, north of the city of Pisa, the evaporation is so high, that the air above the mire is much cooler than in the surrounding with the effect that sensible species of the genus *Sphagnum* can survive there. In South Africa, the large Mfabeni mire is maintained by mist from the

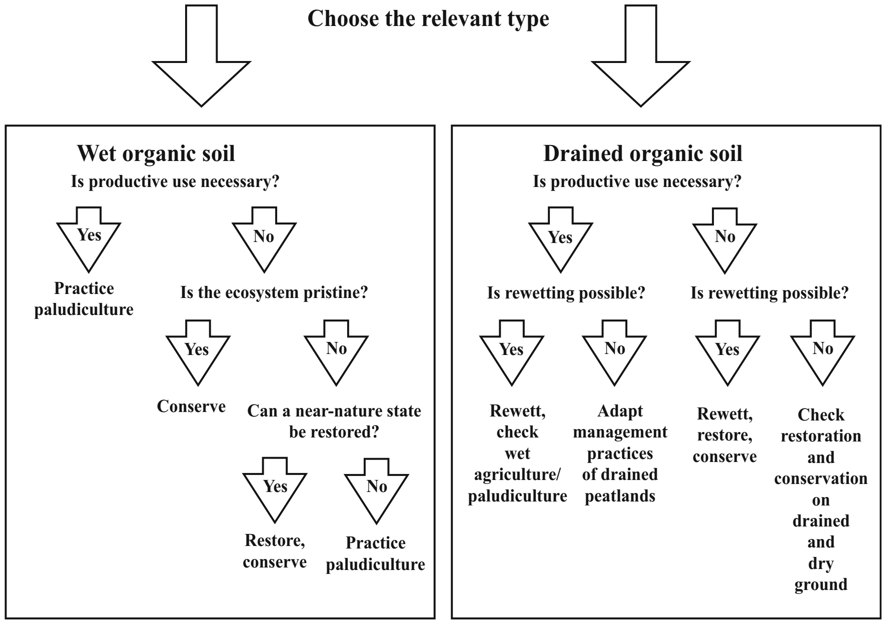

Fig. 1 Decision support scheme for management of peatlands and organic soils. Redrawn and changed from Joosten et al. (2012, p. 8)

neighboring dunes, and the runoff of groundwater is limited by a clay layer under the soil (Grundling 2014; Rapetti et al. 1986; Tomei 1982).

The most common way to restore the hydrology is to stop the irrigation of wetlands by closing the ditches. This is very often done and is the "classic" way to protect mires and fens, as well as swamps. However, this measure has to be done in an appropriate way. It is recommended to lift the water level slowly, so that the growth of the vegetation can follow the rising water level and will not be inundated. Otherwise, the whole mire would be drowned, a large water body would be established and the function of the vegetation as carbon accumulating system would be interrupted for many years or decades.

As Siegel (1988) pointed out, various effects cumulate in the water system of mires. The influx-efflux balance is not easy to detect, as precipitation of rainfall and snow are underlined by groundwater flux. Due to the geomorphological situation each mire has its individual water regime, which is closely linked to the biota in the system. These are not only the visible plant species, but also microbiota, and in some cases also animals, e.g. large herbivores such as elks, animals which build dikes like beavers or animals which destroy dikes, like voles. Thus, the restoration of the water system cannot follow a strict schedule in the sense "one fits all", but has to be adjusted very exactly with respect to the local conditions.

These two examples illustrate the specificity of the situation, in which any protection or restoration must be embedded. In both cases the water level is crucial, and in the neighborhood of the African mire an establishment of new houses should not be allowed. They will reduce the water influx to the basin, in which the mire lies, and extract groundwater. Another danger are fires in the neighborhood, which are common in South Africa, but may not take over to dry peat.

Examples with positive effects for the hydrologic conditions have been examined worldwide. An interesting example from a rather arid area is described from the Tigris and Euphrates rivers in Mesopotamia, Iraque, by Maltby and Acreman (2011). Marshes of 25,000 km^2 were destroyed up to 2000 by 90%, increasing to 93% in 2003, mainly by using the water upstream for electric power and irrigation. Sandstorms, a loss of endangered species, and a loss of a specified agriculture was recorded. After rewetting, till 2005 already 50% of the area could be restored. The re-establishment of the typical biodiversity was recorded.

Utilisation of Peatland Areas

An important strategie in restoration measures of wetlands is the agricultural use through paludiculture (Wichmann and Wichtmann 2011; Joosten et al. 2012). Growing human population requires a sustainable agricultural production, e.g. food production or production of energy plants. In the northern hemisphere fruits such as blueberry, cloudberry or different kinds of cranberry of the genera *Ribes, Rubus*, or *Vaccinium*) or mushrooms are collected. In fens the harvest of grassy plants could support biogas or biofuel production, as well as being used as a source for fibers, which can be used in construction. The traditional use of reed (*Phragmites*) for thatched roofing is widespread.

In tropical peatlands also trees are common, e.g. sago palm or trees for rubber production. A wide range of plants is as well useable as sources for medicinal use. An open canopy of trees is often seen as a positive aspect, as they reduce the transpiration in the lower levels of the vegetation through reducing the wind speed.

Moreover, the use of wetlands for hunting and fishing is an important source for the local population. Some indigenous people are closely bound to the semi-aquatic way of life, for example the Florida Seminole and Miccosucce people in the Everglades (Sturtevant and Cattelino 2004). Other semi-aquatic regions profit from the relatively high productivity as grazing area, e.g. the Ruoergai (Zoige) peatlands on the eastern Tibetan Plateau (Joosten et al. 2012).

And last but not least, many wetlands are a well-known and attractive aim for tourists (Fig. 2). In the northern European or Northern American states hikers are visiting bogs and fens, often on footbridges. The everglades are a legendary touristic region, but also others are well connected. Thus, bogs and fens provide employment as touristic attractions, needing guides, explainers or managers of nature centers.

Fig. 2 Kemeri National Park, Latvia, with raised bogs, fens, small lakes, and groups of trees (photographed by Carsten Hobohm)

Restoration of Mires

Draining of wetlands resulted in dramatic changes in the environmental conditions, structure and assemblages of the vegetation. Well adopted and specialized plants, mainly characteristic bryophytes of bogs, were dramatically harmed by the change of the water regime, and they as well as the accompanying vascular plants are mostly on the Red Lists of the countries.

Conversion of peatland to arable land often resulted in complete elimination of the original vegetation.

For restoration of the original vegetation several treatments are used. In case of existing remains of the natural vegetation, native species can disperse in the surrounding after restoration of the water regime. However, it should be done by a slow, adjusted lifting of the water level, so that the remaining vegetation is not drowned. The results show a great variety in the success (Andersen et al. 2017; Lemmer and Graf 2016). Especially those *Sphagnum* spp. which are responsible for restoring the former raised bog formation, could not be found, only those, which are living in hollows and not on hummocks. This observation was also made by Frankard (2004) in the Haute-Fagnes in Belgium.

In cases of a complete elimination of the vegetation the system of “seeding” plants from other fens or mires is common. This procedure, for example, has been applied in mires after peat mining in North-West Germany. After mining the peat, the surface of the former elevated bog has been down-lifted. Slow up-lifting of the water level leads to large, shallow water areas, in which *Sphagnum* species are imported from other areas, where they are common. The water should be very shallow, so that waves cannot destroy the vegetation layer. However, the most frequent species on these large areas were only four of them: *Sphagnum fallax* and *S. cuspidatum* and the two cotton grasses *Eriphorum vaginatum* and *E. angustifolium.* These are often dominating across hugh areas during the first years after the beginning of restoration activities.

First experiments to cultivate *Sphagnum* species, which are more able to establish hummocks, were reported by Raabe et al. (2018). Under lab conditions the breeding of *Sphagnum* spp. was successful. However, the field experiments are not ready, yet. The cultivated species are rarely found in mires which were peat mined, so that they have to be selected from remaining vegetation with care.

Beside the active support of restoring characteristic vegetation the elimination of non-characteristic plants is another important management tool. The drained bogs are—in case that they are not under agricultural use—invaded by plants, which are not dominating in natural habitats. These are on the one hand different grasses, in Northern Europe especially *Molinia coerulea*, on abandoned grassland also *Juncus effuses* and others. On the other hand shrubs and trees are immigrating. Regionally distributed pioneer trees belong to birch (*Betula pubescens*), willow, spruce and pine species. These immigrants are not only competing for light, but also transpirate much water (up to a few hundred liters per day) and cover the lower vegetation with leaf fall. Appropriate measures to eliminate those plants, or at least minimize their impact, are mowing, grazing, cutting of trees and shrubs.

4 Freshwater Habitats: Running and Still Waters

Freshwater habitats can be classified with respect e.g. to geology and age, geography and elevation, nutrient availability, and others (cf. e.g. Davies et al. 2004; Janssen et al. 2016).

Figure 3 shows an impressive example of a karst spring in Croatia.

Large rivers belong to the putative oldest terrestrial ecosystems on Earth with an uninterrupted history as long as the water is flowing. Some of them changed the flow direction caused by orogenesis millions of years ago. For example, the watershed migration and changing course of the Amazon river during the last 20 Ma is described in Albert et al. (2018).

Settlements, cities and industries have preferably been established along rivers and at the coasts. Freshwater habitats are used e.g. for drinking water, transportation, elimination of waste, and fishery. Fish normally can be caught during the whole year, i.e. also during cold and dry seasons and thus, reduces the risk of malnutrition (Klee 1985; Allan 1995).

Lakes in most cases are relatively young and originated during the late Pleistocene or Holocene, and thus are not very species-rich or rich in endemics. In contrary, a few lakes represent water bodies that exist since a few or many millions of years.

Fig. 3 Karst spring of River Cetina, Croatia (photographed by Michaela Moro-Richter)

E.g. Lake Zaysan (Kazakhstan), Lake Baikal (Siberia), Lake Ochrid and Lake Prespa (Albania, North Macedonia, Greece), Lake Malawi, Lake Victoria and Lake Tanganyika (East Africa), and Lake Titicaca (South America) belong to the putative oldest lakes on Earth. Many large and old lakes are inhabited by endemic animal and rarely plant species. The obvious difference between the amount of endemics in animals and plants in old lakes has to do with the fact that animal species can use more space of the whole water column whereas plants only use the surface water, preferably where the lake is shallow and where they are able to catch enough light. Especially the surface is often more impacted by wind, weather and other influences than the deeper zones. Thus, the possibility and space for an uninterrupted evolution at the surface or in the littoral zone of a lake is much smaller than for deeper zones or the whole water body.

4.1 Endangered Species of Wetlands

Because of a growing world population of humans, enlargement of settlements including building of houses, dams and barrages, and intensification of agriculture, for example, the pressure to freshwater habitats is high and might regionally increase in the future (e.g. Janssen et al. 2016; IUCN 2019).

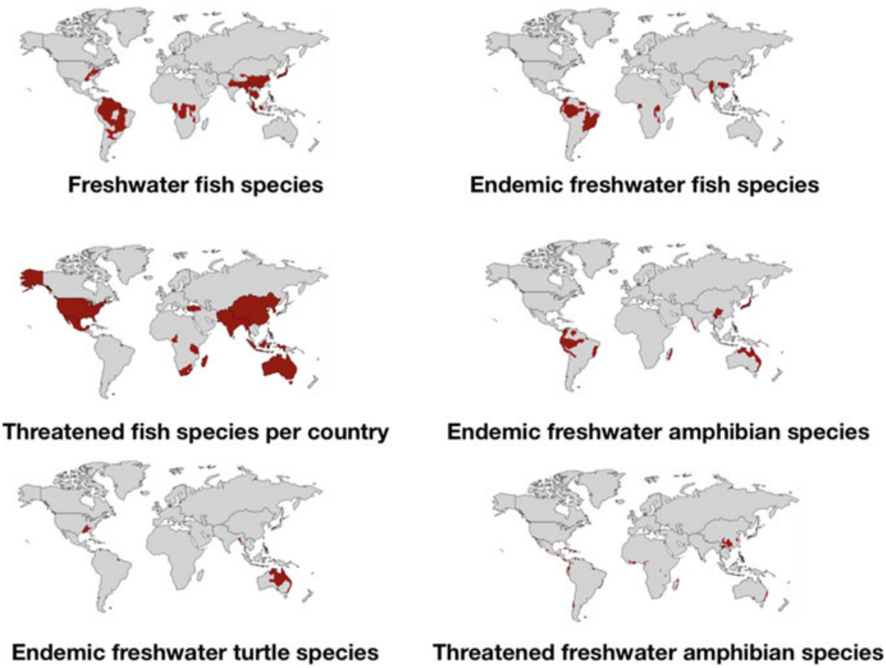

Fig. 4 Distribution patterns of fish, amphibian, and turtle species diversity. The maps indicate numbers of species in total, endemic species, and/or threatened species above certain thresholds per ecoregion or country (FEOW 2019; redrawn by Merel Herdeg). Red colour indicates high diversity

Different groups of animal taxa show high numbers of species, endemics and threatened species in tropical and subtropical regions. These are not only confined to areas with high precipitation rates but also to climates with seasonal rain and low precipitation rates (Fig. 4).

The introduction of alien species in freshwater habitats is often irreversible. Alien species can change the foodweb dramatically in isolated habitats such as islands or lakes. This is often the case if the native foodweb is incomplete and niches have not been occupied during the evolutionary history. If the alien species is representing a new niche, for example predator, then prey organisms can become extinct. If there was a co-evolution between predator and prey prior to invasion the risk of any extinction of a native prey would be much smaller.

For example, many populations of cichlid fish species in Lake Victoria declined dramatically or have become extinct due to a combination of the introduction of Nile Perch (*Lates niloticus*), Nile Tilapia (*Oreochromis niloicus*), Water Hyacinth (*Eichhornia crassipes*), deforestation that lead to siltation, and overfishing. During the last decades more than 200 cichlids in Lake Victoria may have become extinct (Fiedler and Kareiva 1998; Lowe-McConnell 2009; van Rijssel and Witte 2013).

4.2 Freshwater Habitat Restoration

Depending on the kind of anthropogenic pressure to freshwater habitats such as rivers and lakes current restoration measures are numerous. According to a simple internet analysis based on the keywords *wetland restoration*, *freshwater habitat restoration* and *freshwater species conservation* recommended and currently performed measures can be summarized under the headings: water level, flow regime, water quality (1), natural structure and zonation, biodiversity (2), natural functions, ecosystem functions, ecosystem services (3), cause analysis, monitoring, evaluation/assessment (4), strategy, method, investment, cost efficiency (5), legislation, protection, restriction (6), multi-disciplinarity, communication, education (7).

5 Assessment, Challenges and Possibilities

The five most important threat categories for wetland habitats in declining order are pollution e.g. with acidic substances, fertilizers, waste, metal, pesticides and medical device (1), natural system modification, i.e. modification of flow and geomorphology by settlements, establishment of industries, drainings, building of dams, barrages and hydroelectric power stations (2), biological resource use, e.g. fishery and hunting (3), invasive and other problematic species, genes and diseases (4), and agriculture and aquaculture (5). However, some of the threat categories are connected, for example agriculture and pollution (use of pesticides; IUCN 2019, cf. Scheffer et al. 2001, Leppäkoski et al. 2002). Global maps published online in FEOW (2019) display distribution patterns e.g. of threatened and endemic freshwater fish, amphibian, turtle and crocodile species (Fig. 4).

Vörösmarty et al. (2010) analysed threat indices and found a strong relationship between threats to human water security and river biodiversity.

According to the IUCN Red List (2019; cf. Table 1) freshwater lakes, ponds and rivers harbour the majority of threatened wetland species. Smaller numbers are related to mires s.l. and subterranean habitats.

Africa and East, South and Southeast Asia are the continental regions with the most threatened species. Europe represents a little bit more threatened species than S America or Mesoamerica plus Caribbean Islands.

The majority of endangered species is represented by three groups: fish, amphibian and mollusk species.

Numbers of threatened biota are obviously related to both natural richness on the one hand and anthropogenic pressure on the other.

The Habitats Directive (92/43/EEC) and the Water Framework Directive of the European Union (2000/60/EC) implemented the target of a *good ecological status* and a *good chemical status* under *minimal anthropogenic impact*. However, decades after the directives entered into force in 1992 and 2000, respectively, many mires and freshwater habitats across Europe still face serious problems caused by industry and

Table 1 Numbers of threatened species in wetlands (freshwater) with respect to habitat group, geography, taxonomy and threat (numbers according to IUCN 2019; threat categories used: *CR* critically endangered, *EN* endangered, *VU* vulnerable). Note that some of the species can live in more than one continental region or habitat type and may be threatened by a combination of different factors. Thus, some of the numbers are not additive

	CR	CR, EN, VU
Number of threatened species	1518	6026
Bogs, marshes, swamps, fens, peatlands and shrub dominated wetlands	172	869
Freshwater lakes, ponds and rivers	1370	5381
Karst and other subterranean hydrological inland systems	87	384
North America incl. Greenland and excl. Hawaiian Islands	83	314
Mesoamerica and Carribean	169	499
South America	189	694
Europe excl. Greenland	193	732
Africa	396	1644
North, West and Central Asia	100	391
East, South and Southeast Asia	311	1485
Oceania	92	362
Vascular plants	150	681
Fish species	475	1868
Amphibians	338	1245
Mollusks	300	935
Arthropods	170	822
Threatened by residential and commercial development	340	1600
Threatened by agriculture and aquaculture	578	2451
Threatened by energy production and mining	182	809
Threatened by transportation and service corridors	95	438
Threatened by biological resource use	646	2516
Threatened by human intrusions and disturbance	165	681
Threatened by natural system modifications	676	2584
Threatened by invasive and other problematic species, genes and diseases	604	1819
Threatened by pollution	772	2868
Threatened by geological events	52	100
Threatened by climate change and severe weather	269	1010

agriculture, among other factors. For example, round about 40% of the freshwater habitats and 85% of the mires in the European Union are threatened to some degree (Janssen et al. 2016).

The number of critically endangered species which live in wetlands still is extremely high across Europe and on other continents as well (IUCN 2019, cf. Table 1).

Various solutions for the management of wetlands with respect to environmental conditions and natural processes have been published and are currently applied. These are e.g. dismantling of dams or disclaimer of new dams and barrages, regulation of water withdrawal for human use, incentives for the reduction of the use of pesticides, fertilizers and so on, establishment of buffer zones, enlargement and establishment of new nature reserves, and many more.

What are the putative most effective measurements? We hypothesize that the effectiveness of restoration and protection measures might seriously grow if the focus is widened and especially border and transition zones between agricultural land, industrial area or settlement and wetland are included in monitoring and nature conservation programmes.

Defining half of the diameter of a mire, lake or river as buffer zone and more than 10% of the littoral zone as zero-use zone might be a proposal for discussion. The recommended buffer zone may be larger in the case of small and smaller in the case of large wetlands.

The reduction of a short-term profit at local scales caused by regulations can result in long-term profit at larger spatial scales because self-regulated biodiversity and food webs may lead to higher output of ecosystem services, e.g. products of fishing.

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Development and Future of Grassland Ecosystems: Do We Need a Paradigm Shift?

Carsten Hobohm, Monika Janišová, and Hans-Christoph Vahle

Abstract Grassland is the largest terrestrial biome on Earth. It provides important goods and services such as animal fodder (e.g. hay), animal products (e.g. meat, milk and leather), but also ecosystem services such as the contribution to climate regulation, and landscape aesthetics. Last but not least it harbours a rich biodiversity.

Grassland ecosystems are declining in quantity and diversity due to expansion of cropland, urban areas, tree plantations, use of mineral fertilisers and pesticides, suppression of natural fires, overgrazing, undergrazing, intensification of use and cessation of use. Decisions made at regional scales are frequently not strong enough to promote sustainable grassland utilisation and protection of habitats and biodiversity, neither at regional nor at continental to global scales.

We focus on examples from different regions on Earth, the Brazilian Cerrado, Kazakh steppe, and semi-natural grasslands in Europe, and assess environmental conditions including human influences resulting in efficient nature conservation measures. We selected these examples because of their different geographical position and history of use. The examples face very different environmental conditions and evolutionary histories. However, they have in common that the biomass regularly is reduced by grazing, mowing, drought or fire. Without reduction of biomass the biodiversity of many grassland habitats is decreasing and the habitat is replaced by the growth of woody plants and forest.

With this contribution we want to advocate the discussion about a paradigm shift. For many ecosystems the classic assumption of optimal nature protection is to promote wilderness and natural processes, and human influence should be reduced or totally excluded. However, meanwhile many examples show that human

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influence under certain conditions and depending on the intensity can support nature conservation and biodiversity sustainability. Furthermore, usage means trade, exchange of money and therefore upvaluation of the system compared with a habitat that is not used, and, thus, has no economic value for the people.

We discuss the question how intense human influence should be for grassland conservation by focusing on the first and main goal of the *Convention on Biological Diversity*, i.e. survival of all biota on Earth and stopping the loss of biodiversity. Therefore, if human activities support this goal anthropo-zoogenic influence may be wellcome. In the case of many grassland habitats moderate human influence might promote both the protection and survival of biodiversity and economic aspects that can be translated in payments, i.e. human values.

The examples show that the policy at national or supranational scales most probably will decide about the fate of grasslands outside and inside of national parks and other nature reserves.

Keywords Goods and services · Species richness · Grassland types · Threats · Opportunities · Cerrado · Kazakh steppe · European pastures and meadows

1 Introduction

Grasslands are the largest biome on Earth. They originally covered c. 40% of the terrestrial land (except Antarctica and Greenland). The savannas of Africa (14.5 million km^2) and Asian steppes (8.9 million km^2) contain the formerly largest total area (cf. Table 2).

C. 19% of the world's grassland are found in arid zones, 28% in semi-arid zones, 23% in humid, and 20% in cold zones (White et al. 2000; Gibson 2009).

Grassland habitats can be found almost everywhere. Even where a broad zone of forest is dominating grassland may occur as succession stage between pioneer vegetation and woody vegetation or as an extrazonal habitat on locations too extreme to allow tree growth. Thus, grasslands occur from the Tropics to the Arctic, from lowlands to alpine zones, and at all continents except Antarctica.

Today, grasslands that still exist are more or less heavily influenced by hunting, mowing, grazing, anthropogenic fires, suppression of natural fires, by people collecting herbs, fruits, fungi or something else (Figs. 1 and 2). Thus, almost all grasslands today can be characterized as semi-natural grasslands with a modified species-composition. Not only species composition and structure, the food webs have also changed during historical times.

Grassland ecosystems are conditioned by a combination of certain climatic factors, for example mean monthly temperatures between (<-50) -20 and 30 (>40) °C and precipitation totals between (100) 200 and 2000 (2500) mm per year (cf. Schimper 1898; Walter 1990; Gibson 2009). However, these values are also characteristic for many forest and other habitat types across the world.

Table 2 Extent and protected area of grasslands [selection and numbers according to Dziewulska (1990), White et al. (2000), Henwood (2010), Sano et al. (2010), Rachkovskaya and Bragina 2012, Smelansky and Tishkov (2012), European Environment Agency (2017), Bonanomi et al. (2019). Not all habitat types which according to references are summarised under the term *grassland* are included here (cf. left column)

Grassland region	Area of pre-industrial extent (km^2)	Remaining area (%)	Area protected (%)
North America Tallgrass Prairie	600,000–677,300	1–3	0.5
North America Mixedgrass Prairie	628,000–835,700	36–40	1.5–2.6
North America Shortgrass Prairie	181,790–190,900	40–48	8
South America; Northern Paramo, Central Paramo and Puna, Pampas, Campos, Patagonian steppe	2,325,700	>48	5.6
Brazil; Cerrado	2,000,000	20 favourable, 42 used as pasture and for charcoal production	2.85
S Russia, Eurasian grazing lands, steppe geographical zone including forest steppe and semi-desert	2,300,000	20–30	0.11
West Asia; Kazakh steppe (Kazakhstan)	1,214,653	36 (widespread moderately used as pasture)	1.3
East Asia; Mongolia, China, Amur Basin (Russia)	4,308,760	58–60	30
Africa; Sub-Saharan grasslands and savannas	14,860,590	73	?
Southeast Australia, and New Zealand	142,430	25–26	2

One of the most important factors maintaining grassland is the regular reduction of aboveground biomass by grazing, mowing, cutting shrubs and trees, drought or fire.

Many herbivores prefer to feed on leaves of trees, shrubs, herbs, or branches of woody plants. Grassland often is the leftover of all grazing and trampling animals in combination with effects of the abiotic environment. Many grasslands are dominated by grasses but harbour a much richer diversity of herbs, with young woody plants inside. Without regular reduction of biomass—except in the very dry or highly dynamic regions—the succession tends to scrubland, woodland, and finally a more or less dense forest. In many grassland regions planted trees can grow properly.

With this contribution we review environmental conditions, goods and services, threats, opportunities and real perspectives for the survival of grassland with their inhabitants.

We want to pronounce that anthropogenic influences in grassland ecosystems can have positive effects on the biodiversity and survival of the biota. Moreover, most

Fig. 1 Species-rich mesic meadow in the remote village Sarata, Chyvchyny Mountains, Ukrainian Carpathians (photographed by Monika Janišová)

Fig. 2 Haystacks, Apuseni Mountains, Romanian Carpathians (photographed by Monika Janišová)

grassland ecosystems enable little or moderate human influence and use without any risk for the survival of their biota.

2 Wild Herbivors, Human Influence and Trends in the Livestock Sector

Hunting cultures in many parts of the world have set fires to expand open landscapes. Controlled fire was used by humans (huminids) at least since 0.2 but most probably since more than one million years. Since people domesticated horse, cattle, goat, sheep and pig they also used forest and felled trees to expand pastoralism (James et al. 1989; Poschlod 2015).

The ecology of grassland is connected with the ecology of wild and domestic herbivors. However, during the last decades grasslands declined in quantity, the number and mass of wild herbivors such as ungulates decreased and the number of domestic animals increased dramatically. The global mass of livestock today (c. 0.1 Pg C), dominated by cattle and pigs, is estimated 15 times larger than the mass of wild mammals in both terrestrial and marine ecosystems (0.007 Pg C; Bar-On et al. 2018). However, currently an increasing number of domestic animals is bred indoor.

Nomadism dropped almost totally, and was replaced by transhumance or settledness. Transhumance is a practice of moving lifestock in a seasonal cycle, typically to lowlands or other warmer regions in winter and highlands or other less productive regions in summer. The herders normally live in houses but are absent for weeks or months a year to manage their migrating livestock. During this time they may live in yurts, tents, cars or other quarters.

According to the FAO statistics, the meat and milk production increased more or less continuously in both developing and developed countries during the last decades. Livestock breeding has been an important force of deforestation in S America and overgrazing also in other regions (http://www.fao.org/3/i2490e/i2490e03c.pdf; assessed 17/5/2019). Almost all nomadic and moderate-intensity systems with low influence on the natural species diversity collapsed while intensification on the one hand and abandonment on the other were the consequence of settledness and intensification of crop production.

Today, the demand for livestock products such as meat and milk is stagnating in developed countries whereas in developing countries the consumption is increasing due to population and income growth. As a consequence the production and trade is increasing in both developed and developing countries (Thornton 2010).

However, increasing numbers of cattle, sheep and goat do not automatically mean overgrazing in grasslands since also the composition of food and husbandry conditions are relevant. In many regions of Europe but also in parts of Asia, Africa and the Americas the interest in using grassland and the number of domestic herbivores in the landscape decreased during the last hundred years (Pärtel et al. 2005; Hirata et al. 2018) while the whole number of livestock increased. In former times domestic animals got their food directly from woodland and grassland, today they are increasingly fed with concentrated food from cropland. Domestic animals in industrial farming areas in temperate zones are progressively captured indoor and fed in stalls. Denmark and Germany are among the largest pig and pig meat industries in the world, but it is hardly possible to see any pig in the Danish and German landscapes. All over Europe the number of cattle, sheep and goat in the landscape decreased during the last decades.

The *Grazing livestock density index* (cf. Eurostat on the internet: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Grazing_livestock_density_index; assessed 2/2019) measures the stock of herbivors (cattle, sheep, goat, horse) per fodder area. *Fodder area* consists of arable land with cultivation of fodder crops and permanent grassland. Thus, this index does not give any information about how many domestic animals are grazing outside in the landscape. While the majority of domestic animals in Europe hundred years ago lived in the pastures for most of the year cattle (and pig) in the industrial agriculture today often do not see any daylight in their short lives. We estimate that the number of domestic herbivors grazing in European landscapes declined by a rate of more than 90% during the last 100 years. Unfortunately, it is difficult to get reliable information about the development of numbers of domestic and wild herbivors in the landscapes.

To summarize, the influence of wild herbivors on grassland ecosystems historically was more and more replaced by domestic and alien animals with the effect of extinction and endangerement of several native species. Nomadism and transhumance were substituted by settledness, and widespread moderate grazing pressure of both wild and domestic animals decreased and was frequently replaced by one of the two extremes—intensive use with overgrazing or abandoment.

3 Goods and Services

Grasslands are used for livestock breeding, hunting of wild animals, for hay production, collecting herbs, fruits, roots, and fibre. Since usage means also upvaluation of the ecosystem, and because grazing or mowing are essential for the existence of many grassland ecosystems the relinquishment of human influence including livestock breeding can mean both devaluation and destabilization.

Grasslands are an important source of non-commodity products such as water quality, climate regulation via carbon storage and evapotranspiration, aesthetics, recreation, and biodiversity conservation (Kulshreshtha et al. 2015).

The aggregates of the soils under grassland are in average more stable than soils of arable land. In combination with a higher field moisture capacity this results in a much better water retention. Thus, inundations and heavy rain have less strong erosion or washout effects in large grassland than cropland regions (Klapp 1954; Buchgraber and Gindl 2009).

Various studies calculated the potential of marine and terrestrial ecosystems to accumulating carbon in the biomass, soil, or water. Permanent grasslands with their roots, soil vertebrates and invertebrates, bacteria, fungi, humus and exchange processes have a great potential to take carbon from the atmosphere and store it in the soil and biomass. The meaning and potential of the above- and belowground carbon storage in grassland ecosystems was already indicated and estimated by Olson et al. (1983). If grasslands accumulate round about a third of the carbon of all terrestrial ecosystems and if the reservoir of all terrestrial soils is two or even three times larger than the amount of carbon in the atmosphere then grassland might be a relevant sink for the future (Boeker 1957; White et al. 2000; Gruber and Sarmiento 2002; Lal 2008; Gruber et al. 2009; Archer 2010; Bond-Lamberty and Thomson 2010; von Haaren et al. 2010; Bar-On et al. 2018; FAO 2018).

However, in regions with frequent wildfires an increasing carbon sequestration in the biomass and soil would require the elimination of fire which on the other hand causes a serious loss of biodiversity (Abreu et al. 2017). Thus, increasing carbon storage should only be discussed for grassland, scrub or forest where fire is not a natural event and may not become a mega-fire event because of the storage of carbon.

Not only philosophers but also ecologists, physicians, landscape planners and architects pronounce the meaning of the landscape scenery for place identity, tourism, recreation activities, and health (e.g. White et al. 2000; BMU & BfN 2010).

If we observe the relationship between objective landscape attributes and the subjective aesthetical awareness then we can recognize positive and negative relations. A positive effect is described by terms such as beauty, sympathy, attractiveness, wellbeing, and a negative reaction is related to effects in our awareness that make us unhappy, nervous, or hurt.

Most likely, noise, fetidness, but also artificial buildings (at least p.p.), roads, streets, smog of light, rectangular and linear shapes in high concentrations are affecting the landscape aesthetics at the uncomfortable side (Milton 2002; Brady 2003).

In contrary, colourful and species-rich open and half-open landscapes without rectangles or linear dissections by trend are perceived as attractive. We hypothesize that grasslands in combination with water, large animals, woody plants, scrub, groves, or small woods are experienced as highly attractive by most people. Eventually this might have to do with our evolutionary origin in half open landscapes such as savannas. This hypothesis is underlined by the arrangements of private gardens and public parks all over the world (Parsons 2008; Zalta et al. 2016).

Therefore, the loss of quantity and quality of grassland habitats is directly linked with a loss of physical, environmental and emotional values and with a limitation of recreation possibilities (Bundesamt für Naturschutz 2014).

Fig. 3 Paramo with *Espeletia grandiflora* in Colombia, west of Bogota (photographed by Carsten Hobohm)

4 Species Richness

Species richness depends on spatial scale, species concept, calculation mode, and the group of organisms considered. The following examples may give an impression about the species richness related to grassland ecosystems in the world.

Many grassland ecosystems such as the grasslands of the high Andes (Fig. 3), Central Chile, and Southern Patagonia rank highest for the biological importance of Endemic Bird Areas (White et al. 2000).

More than 1300 vascular plant species, which are endemic to Europe, are associated with grassland habitats; only endemics related to rocks and screes are more numerous (>2700). Scrub and heath take position number three (>1100), followed by forest with c. 770 endemic vascular plant species. Other habitat types represent lower endemism (Bruchmann and Hobohm 2010; Hobohm 2014).

At local scales (plots <50 m^2) all world records of the plant species richness were determined in grassland habitats. For example, 89 different plant species have been identified in a single m^2 of temperate grassland. This is a higher number than in tropical rainforests or in any other habitat type of the same plot size (Wilson et al. 2012).

Table 1 Grassland typologies (highest level of order)

Grassland types	References
Meadow, steppe, savannah (with isolated trees)	Schimper (1898)
Savanna and parkland (tropical/subtropical), steppe and prairie, meadow, pasture, sedge swamp and flush, herbaceous and half-woody salt swamp, forb vegetation	Ellenberg and Mueller-Dombois (1967)
Tallgrass prairie, shortgrass prairie, mixed-grass prairie, shrub steppe, annual grassland, desert (arid) grassland, high mountain grassland	Laycock (1979) for North America
Tropical lowland grassland, tropical montane grassland, savanna & scrubland, Mediterranean grassland & forb meadow, temperate grassland, meadow & scrubland, boreal grassland, meadow & scrubland, cool semi-desert scrub & grassland, alpine scrub, forb meadow & grassland	Faber-Langendoen and Josse (2010)
Dry grassland, mesic grassland, wet grassland, alpine grassland, tall-herb fringe, saline grassland, wooded grassland	Janssen et al. (2016) for Europe

5 Grasslands Types

Schimper (1898), Ellenberg and Mueller-Dombois (1967), Laycock (1979), Gibson (2009), and Janssen et al. (2016), for example, distinguished different grassland types and ordered them in relation to soil conditions (wet, dry, eutrophic, oligotrophic, etc.), climate (arctic, boreal, temperate, subtropical, tropical, arid, humid), structure (tallgrass, shortgrass, shrub steppe), use (pasture, meadow, fertilized, unfertilized, etc.), or other aspects (Table 1).

Some terms describing grassland types are geographically restricted. The term *prairie* is a French word that is preferably used for grassland in North America. Vast plains of grassland in S America are called *pampas* (Quechua for plain).

The term *savanna (*or *savannah)*, Spanish sabana, is originally a word from native Indians (Taino) from Cuba, the Caribbean and/or Florida (zabana) which is commonly associated with Africa and large migrating herds of wild herbivores. It is not very common to use this term for structurally similar park grassland units in Eurasia or Australia.

Alpine grasslands are very similar to grassland of the tundra at high latitudes. However, it is not very common to call vegetation of high mountain zones *tundra vegetation*.

Meadows are normally mowed for haymaking. In some cases the term is also used for natural grassland.

6 Threats

Grassland is endangered by direct conversion to other habitat types such as cropland, tree plantation and urban habitat, by intensification of use or abandonment. These are the most important threats to grassland all over the world. Temperate grasslands have experienced heavy conversion to agriculture, more than tropical and subtropical grasslands (White et al. 2000).

The quality and diversity of grasslands is endangered by intensification, fertilization, the use of pesticides which enable a higher stocking rate or mowing frequency. In many grassland regions an increasing stocking rate leads to overgrazing and desertification as a result of trampling and foraging. Also in meadows intensification of hay production leads to declining biodiversity. Grasslands that are fertilized and several times per year mowed often look like a golf course.

However, in many regions grasslands also disappear because of abandonment. The relinquishment of pasturing or hay production in the case of diverse semi-natural grasslands leads to a succession where grassland becomes replaced by scrub and forest growth.

The decreasing grazing pressure or absence of domestic animals in the landscape in combination with a reduction of hay production is one of the most serious problems for the survival of grassland in Europe today (Janssen et al. 2016).

Worldwide nature reserves and national parks are one of the most important legal instruments in conservation politics and management. Several international nature conservation organisations claimed a legal protection of 10% per biome or habitat type as minimum (Henwood 2010). Table 2 shows that grasslands in many regions on Earth are far away from reaching this goal.

However, also nature reserves cannot guarantee the survival of high-nature-value grassland in every case. For example, round about 21% of Western and Central Europe (i.e. EEA member countries and cooperating countries, cf. European Environment Agency 2012) belong to the Natura 2000 network including many directly protected National Parks or other types of nature reserves. A lot of these areas contain high-nature-value (HNV) grassland and most of the HNV-grassland types are protected under European law (Habitat Directive).

However, also in these regions the survival of many grassland types and their biodiversity is not guaranteed. In Europe, mires and grasslands belong to the most threatened habitat types (Janssen et al. 2016). To date, the prominent idea of National Parks is wildlife and thus, zero human influence. In regions without wild herbivors or fire like in many parts of temperate Europe species-rich grasslands in National Parks would disappear because of succession if human influence relinquishes.

We here want to discuss if we need a changing paradigm focusing on the main goal of the CBD, i.e. survival of all biota, preventing the loss of biodiversity. And if human activities support this goal anthropo-zoogenic influence may be wellcome. In many regions and habitat types, however, also wilderness might by a reasonable way to reach this goal.

7 Examples: Brazilian Cerrado, Kazakh Steppe, European Pastures and Meadows

The examples were chosen because of a variety of reasons, e.g. their different geographical position and evolutionary history, different climates, and different human history, influence and regulations. The Cerrado is located in the tropics, representing hot or very hot summer and relatively high precipitation rates (800–2000 mm/year). The winter normally is mild or even warm. The Kazakh steppe and the European pastures and meadows are in the continental and subatlantic temperate (or Mediterranean) zones, respectively. The European grasslands normally receive higher precipitation rates (>600 mm/year) than the Kazakh steppe (200–400 mm/year). Frost during the winter in Eurasian temperate regions is quite common.

The frequency of fire is highest in the Cerrado, intermediate in Kazakhstan, and unimportant or close to zero in semi-natural grasslands of Europe.

Regulations for agriculture have altered and still threaten the natural or semi-natural species compositions in each of the examples. Laws and organizations for nature conservation are established to minimize the damage.

Fig. 4 Species-rich landscape of the Cerrado near Alto Paraiso (photographed by Carsten Hobohm)

Fig. 5 Maize production and plantation of eucalypt (background to the right) north of Brasilia in the Cerrado region (photographed by Carsten Hobohm)

7.1 Brazilian Cerrado

The Brazilian Cerrado (Fig. 4), located between the Equator and Tropic of Capricorn covers an area of approximately two million km^2.

Most geological substrates are extremely old rocks of the Precambrian (gneiss, schist, granite) and Palaeozoic and Mesozoic basalt, sandstone, and shale. The soils are predominantly well-drained, acidic, extremely nutrient-poor, and rich in aluminium and iron oxides (oxisols). Other soils are ultisols, very sandy or shallow entisols, and cambisols.

Without fertilization grazing by livestock was almost impossible because the nutritional value of the landscape was too small, the animals did not grow properly and became ill.

These naturally poor soils can be converted and used as cropland with little effort because the Cerrado biome is naturally moist (Fig. 5). Thus, most regions only need the supply of nutrients (e.g. P, Mg, and replacement of extractable aluminium via addition of Ca) but no irrigation. This is the reason why the exploding development of agriculture in the Cerrado biome since 1960 has become the largest after the movement in the Middle West of the USA during the nineteenth century (Lepsch 2016).

The Cerrado is an ancient biome. Prototypic formations may have existed during the Cretaceous. A dynamic relationship between forest and grassland has been determined for Pleistocene glaciation cycles. During cold periods grasslands expanded and forests contracted while the opposite happened during warm periods. The long evolutionary history in combination with the large area occupied is the reason for the huge biodiversity with a high rate of endemism (Ratter et al. 1997).

With annual precipitation rates of 800–2000 mm most Cerrado ecosystems belong to the moist savannas. Surprisingly, this amount of rain is comparable with precipitation rates of the adjacent Atlantic rainforest (Mata Atlantica; 1200–2500). Thus, many regions of the Cerrado biome have similar or the same precipitation rates as many regions of the Mata Atlantica. Furthermore, also the average temperatures are comparable, with 18–27 (28) °C in the Cerrado biome and 14–26 °C (high mountain zones excluded) in the rainforest of the Mata Atlantica.

Thus, equivalent precipitation rates and temperatures enable the occurrence and neighbourhood of tropical rainforest near the coast and Cerrado biome as totally different landscape more inland.

In contrary to the rainforest of the Mata Atlantica the Cerrado is characterized by a strong dry season between April and September. During this time frequent natural fires impact and destroy primarily woody plants, trees and shrubs. Thus, fire is essential for the existence of Cerrado grasslands and savannas.

The Cerrado contains a very rich flora compared to other savannas. It harbours c. 10,000 native vascular plant species of which 4400 are endemics, 195 species of mammals, 605–837 bird species, 225 reptiles and 251 amphibians (Oliveira and Marquis 2002; Mittermeier et al. 2005; Mendonça et al. 2008), many of them endemic.

Furthermore, Ratter et al. (1997) found remarkably rich biodiversity patterns at landscape scales (beta diversity). They analysed the woody vegetation of 98 sites throughout the whole region and identified 534 species of vascular plants inside the plots. 158 (30%) species were found in a single site only while 28 species were present in 50% of the plots or more. None of the species was found in all plots.

In contrary to African savannas, large herds of migrating herbivores are absent. Most mammal species in the Cerrado are small or medium-sized and show different adaptations to fire and the local compositions change much as a function of time after fire (Briani et al. 2004).

Human activities threaten the Cerrado biome. Strong impacts are conversion to cropland, using the land as pasture for domestic animals, forest growth including tree plantations, e.g. of exotic trees such as eucalypt (Fig. 5), traffic and building activities, and fire prevention (Ratter et al. 1997; Durigan et al. 2007; Válka Alves and Janišová 2016; Janišová et al. 2016).

There is a long discussion about fire prevention and the meaning of the so-called *zero-fire policy*. Meanwhile it became evident that exclusion of regular fire enlarges the risk of mega-fire events caused by continuous accumulation of flammable material such as litter and timber for a long time. Thus, like in Mediterranean regions of California where trees such as eucalypt and pine are planted, zero-fire policy would bring more damage than benefits for Cerrado ecosystems (Fidelis et al. 2018).

The competitive impact of invasive African grasses such as *Melinis minutiflora* or *Urochloa brizantha* has been described by Durigan et al. (2007) and Damasceno et al. (2018).

C. 97% of the Cerrado area is private or indigenious land which is not managed by federal or state agencies. Only 2.85% of the biome is formally protected as nature reserve or national park. Most Indian reserves (4.1% of Cerrado) harbour grassland and savanna under relatively favourable conditions and with little impact on the natural environment. Private landowners are by law required to leave a minimum of 35% of their land to support wildlife and nature conservation. However, many landowners have more than one private area. And the private lands are sometimes very distant. Thus, the farmers can decide where they want to intensify agriculture and where they want to set aside 35% of their rural properties as legal reserves. As a consequence Cerrado vegetation in the hot North are much less destroyed than in regions to the South where the conditions for cropland are better.

Thus, also here the interpretation of what is needed or allowed, the expansion of agriculture, timber production, forest growth, the introduction of exotic tree plants (eucalypt for charcoal production), and the control of fire is a matter of political specifications (Válka Alves and Janišová 2016; Janišová et al. 2016; Bonanomi et al. 2019).

Fig. 6 Semi-desert steppe in SE Kazakhstan with *Rheum tataricum* and *Artemisia* spp. (photographed by Carsten Hobohm)

Fig. 7 Kazakh steppe with *Tulipa schrenkii* and *Stipa capillata* (not flowering) in Kurgaldzhinskii Reserve (photographed by Carsten Hobohm)

7.2 Kazakh Steppe

The temperate steppe biome of Eurasia, stretching from Central and E Europe (Romania, Bulgaria, Ukraine) to E Asia (Mongolia, China), is the largest temperate grassland belt on Earth (Table 2). It is composed by four main biogeographical sections, the Pontic-Caspian steppe to the West, the Kazakh steppe in the central part (Figs. 6 and 7), the Mongolian steppe to the East, and the S Russian steppe to the North. However, other smaller steppe areas occur outside of the zonal steppe regions in temperate Eurasia, for example in dry parts of the Alps, Caucasus, or in other mountain ranges and neighbouring countries of Europe and Asia.

In Europe only 3–5% of the steppe, in S Russia c. 20–30%, and in E Asia c. 58–60% remains in a natural or semi-natural state. In the Kazakh area about a third (36%) of the former steppe area still exists under more or less adequate conditions, i.e. low anthropo-zoogenic influence. For the whole biome c. a third of the former steppe can be assumed as still existent with plus or minus natural species compositions of vascular plants. However, even in regions with rich and/or natural vegetation the composition of vertebrates is another one than hundred years ago. In the South of Kazakhstan the last lions were shot in the 1960s.

The Kazakh (real) steppe covers c. the northern third of Kazakhstan with an extension of 2200 km from East to West. Most of the steppe lies in Kazakhstan, the north-eastern part extends to regions in S Russia and connects the Kazakh with the Russian steppe.

The grassland is naturally replaced by woodland and forest under more humid conditions and at higher elevations. In the transition zone a forest-steppe with a structure similar to an African or Cuban savanna occurs. In dryer regions to the South the steppe merges into semi-desert scrub. Steppe and forest-steppe together occupy c. 45% of Kazakhstan (Rachkovskaya and Bragina 2012).

Precipitation rates range from 200 to 400 mm per year in average, with a little bit higher monthly rainfall during summer. However, there is no real dry period over the year.

Mean temperatures in January range from −10 to −20 °C, the summer is warm or hot with average temperatures between 20 and 25 °C in July. Record low in Astana/Nur-Sultan was −52 °C, highest temperature was 42 °C (DWD 2002). The temperatures can also fluctuate a lot between day and night. From time to time very high wind speed can be measured.

Black and chestnut soils are dominated by different *Stipa* spp. and other grasses preferably in the northern territories of Kazakhstan. Saline soils with high rates of evapotranspiration and many halophytes (div. Chenopodiaceae) are widespread in the depressions. Aeolian sand and loess cover most of the lowlands, paleozoic and mesozoic rocks, screes and stony ground are the dominating substrates of the mountain ranges.

7.2.1 Species and Habitat Type Diversity

The flora of Kazakhstan contains c. 6000 vascular plant species, the steppe flora c. 2000 species (Abdulina 1999; Rachkovskaya and Bragina 2012).

Habitat types and species compositions differ in relation to climatic conditions (e.g. precipitation rate), vertical zonation/altitude/slope, substrate/soil, impact of humans (e.g. mowing), and wild and/or domestic grazing animals.

In the Kazakh steppe different habitat types such as forest steppe (light, humid), meadow steppe (non-forested patches in the forest steppe zone), real steppe, semi-desert steppe (dry) in the lowland or in the mountains, on aeolian sand or loess, stony or rocky ground, and on saline soils can be distinguished (Rachkovskaya and Bragina 2012). In N Kazakhstan the precipitation rate is normally higher and the temperatures are lower than in the south, i.e., that also the time with a snow cover is longer in the north than in the south. However, because of the higher humidity the productivity in the north is higher than in southern regions of the country.

7.2.2 Anthropogenic Influences in the Past and Present

Alpine zones of the Tien Shan, Altai Mountains, and lowland steppe were traditionally used as pasture for domestic herbivors by nomadic people. Migrations span up to 700 km in the semi-desert and steppe.

Because of the short vegetation period, cold and the high snow cover in the northern parts and high mountain zones wild ungulates, livestock, nomadic people, and also other groups of animals (birds, insects) visited and used the northern and high mountain regions only during summer. In autumn and winter they migrated to winter pastures with low snow cover in the semi-desert and dry steppe zones of the S and in the lowlands.

In general, Russians and Europeans in Kazakhstan promoted crop cultivation while Kazakh people traditionally lived as nomads. Even before the 1917 revolution and during the collectivisation in the 1930s the pressure of agricultural intensification lead to reduced mobility and a strong decrease of the number of domestic animals.

During the 1940s a limited form of nomadism was allowed, and nomadism in the context of the Soviet system of collectivisation continued until the early 1990s (Robinson et al. 2000).

During the 1950s vast areas (up to 40%) of summer pastures were converted to arable land accompanied with the construction of irrigation systems, and the nomadism was largely replaced by collective farms. However, in many regions the cultivation of crops on ploughed ground failed, and naturally dry conditions in combination with high wind speed and a declining groundwater level damaged the crop cultivation. As a result deserted and weed-rich fallow lands followed.

In the 1960s, whole Kazakhstan was partitioned and the use was defined and controlled by the authorities of the country and the management of the collective farms (Robinson et al. 2000).

Since the Soviet period many pastoralists lived in houses during winter times and in yurts during the summer. In the end of the Soviet period in 1987 the process of de-collectivisation started and the transformation of state farms to private farms was finished in 1993. However, also in the end of the millenium most farms had a kind of collective structure. An important result for the landscapes was a strong decline of the number of sheep by c. 70% with the result that most summer pastures and winter pastures far away from villages were empty (Robinson et al. 2000).

Today transhumance and nomadic activities are extremely reduced. Modern systems of livestock farming often leads to overgrazing around settlements and watering points, and undergrazing in other areas.

The composition of wild ungulates and other vertebrates is highly impacted by the composition and fragmentation of landscape elements, crop production, pastoralism and hunting. The last tiger in Kazakhstan was recorded in the year 1948 (Heptner and Sludskij 1992).

The Saiga antelope (*Saiga tatarica*) at the end of the Peistocene lived in many regions of the Eurasia, including W Europe, and even on Great Britain. Because of fragmentation of the steppe, hunting and using horns for medicine in China, and because of mass mortalities the whole population declined from several million animals to several ten thousands, with the majority today living in Kazakhstan. In 2003 only 23,000 animals survived in Eurasia. In 2018 the population of Kazakhstan (94% of all Saiga antelopes) was estimated as 154,600. However, severe winter or drought, poaching for horns and a disease outbreak can reduce the population again very fast (iucnredlist.org; assessed 24/5/2019).

Fig. 8 Cultural landscape with different types of grassland (painted by Hans-Christoph Vahle)

Especially in dry years, natural and anthropogenic fires are frequent. In wet years parts of the steppe are traditionally mowed.

7.3 European Grasslands

It is not easy to find serious numbers for the pre-industrial extent of grasslands in Europe (cf. Table 2). This has to do with the fact that most parts of Europe are in the forest zone. Wild herbivors have widened the open landscape for at least 1.8 million years. During Pleistocene glaciation cycles grasslands expanded and contracted due to cooling and warming while the range of forest changed in the opposite direction. However, after the last glaciation period wild herbivors were increasingly repressed and partially eliminated. During the Holocene, for example, the European Ass (*Equus hydruntinus*), the Irish Elk (*Megaloceros giganteus*), the Wolly Mammoth (*Mammuthus primigenius*), the Wolly Rhinoceros (*Coelodonta antiauitatis*), the Auerochs (*Bos primigenius*), different subspecies of the Portuguese Ibex (*Capra pyrenaica*), and the Tarpan (*Equus ferus ferus*) went extinct, most probably as a result of hunting. At the end of the Pleistocene also the Saiga antelope (*Saiga tatarica*) lived in Europe, even in Great Britain. During the Holocene, grasslands were more and more intensively used with grazing livestock (domestic cattle, sheep, goat, horse), and by mowing and hay production (Figs. 1, 2, 8, 9, 10, and 11; Pärtel et al. 2005).

Fig. 9 Montane meadow with *Arnica montana* on siliceous ground in the Central Alps. The plant community is maintained by low intensity of mowing (painted by Hans-Christoph Vahle)

Fig. 10 Nutrient-poor wet meadow with the orchid *Dactylorhiza majalis* (painted by Hans-Christoph Vahle)

Europe is more than two times as large as the *European Union* which on the other hand has no constant area as the number of member countries varies from time to time. Thus, different calculations of the land cover related to the EU are not comparable. Last but not least, definitions of the term *grassland* differ considerably. These are the reasons why it is difficult to get reliable numbers on the grassland range in Europe for both historical times and present times.

Grazing is historically much older than mowing and has a natural root also in Europe like in most continental regions. The development and use of the sickle and mowing is going back to neolithic or even pre-neolithic times (c. 18,000–10,000 BP; cf. Unger-Hamilton 1985). Most traditionally mowed grassland communities are relatively young and developed during the Middle Ages (Ellenberg 1996; Heinrich 1992; Hejcman et al. 2013; Stebler 1898). Table 3 shows general differences between effects of grazing and mowing of grassland. Pastures normally represent a higher environmental heterogeneity in space than meadows because of trampling and the selection of plants that were fed by livestock. If the nature conservation target would be to reduce biomass and productivity in a long time perspective then it is much easier to succeed with mowing (e.g. Fig. 10). However, under comparable ecological conditions mowing is normally more expensive than grazing (pers. comm. with public authorities).

Fig. 11 Section of nutrient-poor grassland with *Nardus stricta, Briza media, Campanula rotundifolia, Viola tricolor, Hypochaeris radicata* etc. (painted by Hans-Christoph Vahle)

Table 3 Differences between livestock grazing and mowing (refs. see text)

	Grazing/pastures	Mowing (sickle)/meadows
Origin/development	Evolutionary/natural	Pre-neolithic (SW Asia)
Spatial heterogeneity	Higher	Smaller
Maximum species diversity of plants	High at local scales, very high at landscape scales	Extremely high at local scales, very high at landscape scales
Biomass reduction without input of fertilizers or additional food for grazing animals	Small because of nutrient cycling	High because of biomass elimination
Expenses for management	Lower	Higher

During the twentieth century the proportion of grassland vs. arable land changed from grassland dominance to dominance of arable land. Still in the 1970s grassland occupied 38% of the agricultural land in Europe (without Soviet Union; cf. Dziewulska 1990). In 2005 permanent grassland in the 25 member states of the EU (EU 25) occupied an area of c. 516,520 km^2 or 32% of the agricultural land and 13% in total. *Permanent grassland* in the EU is defined as land dominated by herbs and grasses which is not tilled for more than 5 years (Reheul et al. 2007). This definition includes rather species-poor and highly artificial agricultural land, and species-poor to species-rich natural and semi-natural grasslands as well. The high nature value (HNV) grassland today represents a very small proportion of European grassland.

However, round about half of Europe's area (whole Europe including European Russia) is estimated as agricultural land, and less than a third of the agricultural land is covered by permanent grassland (most likely less than 10% of whole Europe; cf. Hobohm and Bruchmann 2009). Most of the remaining grassland today is very species-poor and intensively used. Thus, we do not exactly know how large exactly is the area of Europe covered with species-rich grassland or moderately used half-open landscapes comprising a mosaic of grassland, scrub vegetation and solitary trees (Janssen et al. 2016).

All European countries have signed or accepted (Montenegro in succession) the Convention on Biological Diversity (CBD). Together with the Birds Directive and the Waterframe Directive the Habitats Directive (Council Directive 92/43EEC) forms the corner stone of Europe's nature conservation policy. More than 1000 species and 200 habitat types are directly protected, irrespective of the ownership and even if they may occur in farmland or in a private garden. A network of several thousands of Natura 2000 areas cover 18% of the EU member countries. This is the largest network of localities and regions with a focus on conservation and protection of the nature on Earth.

Nevertheless, the quantity and species richness of European grasslands at local and landscape scales is still continuously decreasing which theoretically is not allowed (Habitats Directive, Article 6).

It is a peculiarity that semi-natural grassland in Europe harbours many endemics and is partially extremely species-rich. Moderately used and mesotrophic grasslands in general are much richer than natural grasslands or even forests in Europe (Hobohm 2014). However, highly fertilized, productive and intensively used meadows are normally rather species-poor as well.

Janssen et al. (2016) distinguish 53 different grassland habitat types in Europe. Especially dry grasslands, mesic grasslands, saline grasslands and wooded grasslands are threatened. The pressure is a little bit lower on wet and alpine grasslands and tall-herb fringes.

The meaning of grasslands in Germany for the survival of plant species is reviewed in Bundesamt für Naturschutz (2014). Almost 40% of the vascular plant species in Germany are associated with grassland habitats. Most insects live in open landscapes, many of them associated with grassland. This is typical, and the situation in other countries of Central Europe is comparable (e.g. Essl et al. 2011).

7.3.1 Loss of Grassland in Central Europe

Despite of intensified nature conservation legislation the area covered with high nature value grassland in Europe is continuously decreasing, due to intensification, abandonment or as result of conversion to cropland (Grund and Weiß 2011; Finck et al. 2017).

Meanwhile not only nutrient-poor pastures and meadows (Fig. 11) are critically endangered but also mesic meadows with moderate fertilization (Fig. 1), for example low and medium altitude hay meadows with *Arrhenatherum elatius* (cf. Janssen et al. 2016; Code E2.2). The animal and meat production in Central Europe is so intensive that the industrial agriculture has to pay for grassland that can be used as recipient for their liquid manure. In some cases, for example in Lower Saxony, this material has to be carried hundreds of kilometers because the landscapes are saturated with urine and *bullshit* in its original meaning.

The main threats are always the same: industrial agriculture, reduction and elimination of landscape structures, fertilization, use of pesticides in the arable land affecting also other habitat types in the neighbourhood.

7.3.2 Biodiversity Between Untouched Nature and Human Use

Most grassland habitats and landscapes in Europe are a product of humans who destroyed most of the virgin forests long time ago and changed the structure almost everywhere until today. Only the highest mountain zones and a few wetland areas are still relatively unviolated. Industrial agriculture and forestry today are extremely productive. A crop failure nowadays is comparable with a bumper crop no more than a couple of decades ago (cf. FAO for crop yields; http://www.fao.org/faostat/en/#data/QC).

Would it be a good idea to protect landscapes from human influence? The answer is yes and no, and depends on the primary nature conservation goal. If the goal is wilderness and reduction of human influence then national parks might be the right decision. If the goal is species conservation and zero species loss (CBD) then grasslands in Europe are extremely important and most of them must be maintained by grazing or mowing. Ruprecht (2012) has described how steppe-like grasslands in Central Europe decreased by management cessation. Interestingly, Smelansky and Tishkov (2012) discussed not only overgrazing as main reason for the degradation of the Eurasian steppes of Russia but also undergrazing. They showed that undergrazing can lead to decreasing species diversity also in the Eurasian belt of natural grasslands.

Without use the succession of grassland in Europe normally would lead to scrub and afterwards to woodland and forest. Indeed many grasslands were not only converted to cropland but overgrown by forest or replaced by tree plantations in marginal agricultural regions. Often low productive grassland habitats in the second half of the twentieth century were covered with Christmas trees (such as *Picea abies*, *Abies alba*, *A. nordmanniana*).

Thus, humans in Europe are responsible for the survival of the biodiversity in both natural and semi-natural habitat types. As a consequence *no influence and wilderness* and *no species loss* should be arranged in different landscapes, regions and nature protection categories (Janssen et al. 2016).

Farmers in the European Union today can protect species-rich grassland if they are paid for it. Otherwise they are outcompeted. In a few cases farmers use the grasslands without fertilization and in a traditional manner because they are idealists and want to preserve the beauty of the landscape.

Thus, nature conservation of grassland in Europe needs a comprising policy respecting public goods and services and the demand of the farmer.

These should also focus on the health of the animals, on animal welfare and their natural medicine in the grassland, on the quality of the products, i.e. meat, butter and milk, and on beneficial organisms such as insects. Furthermore, the diversity in the landscape might reduce the risk of crop failure caused be severe weather. This was visible in Central Europe in 2018, where a long and hot drought caused serious failure in the agriculture and organic farming was obviously less affected (pers. comm. with authorities from agriculture administration in Lower Saxony).

The importance of species-rich hay for the health of domestic animals was for a long time part of the traditional knowledge. Farmers used hay of species-poor grassland on nutrient-rich ground as energy-rich fodder, they used species-rich grassland of nutrient-poor ground for the health of the animals, and they used hay of species- and energy-poor grassland of mires—dominated e.g. by *Molinia coerulea*—as bedding material in the stables. In spring the mixture of excrements and old hay was transferred from the stable to the cropland as nutrient supply. We did not find any indication that grassland before the twentieth century was regularly fertilized.

In many agricultural landscapes across Europe species-rich grasslands are already totally destroyed. Only old local floras and checklists tell how species-rich the landscapes must have been during former times. However, a few examples show that under certain ecological conditions it is possible to restore such high nature value grasslands.

Therefore, it could be useful to transfer hay from the surrounding to provide seeds of target grassland species to the restored field and to develop an optimal management regime to enable the long-term coexistence of multiple species at the place. However, keeping existing HNV grasslands is always a better and cheaper solution than restoring what was destroyed before.

7.3.3 Transforming Cropland to Grassland

Meadows with *Arrhenatherum elatius* which normally grow on mesotrophic to eutrophic ground have been re-established in a rather short time on former eutrophic soil of farmland. One or two years after transmission of hay it was possible to produce relatively species-rich and healthy hay of high quality (Bosshard 1999).

The establishment of grassland on formerly tilled ground was performed e.g. in the Ruhrgebiet, North Rhine-Westphalia. The goal of the project was the production of healthy hay. Thus, the economic goal of hay production was combined with the European goal to protect a threatened habitat type (FFH 6510, Habitat E2.2 of the European Red List of habitats). In this case the habitat type was re-established with transmission of regional hay.

Three years after establishment a typical species combination and hay of high quality could be asserted. Meanwhile, the meadow is older than 10 years and the species richness is still increasing. Another example in W Germany shows that under certain conditions also eutrophic soils of arable land can be used to re-establish low-productive and species-rich meadows (Vahle, not published, yet).

Until 1996 a horticultural area on loess loam was covered with dung and liquid manure and used as vegetable garden. In 1996 seeds from a nutrient-poor grassland were sowed. Because of the high density of seeds (50 g/m^2) a typical grassland composition already occurred in the first year. Afterwards the grassland was mowed twice a year.

For the whole time of 20 years after the beginning of the project a typical meadow of relatively nutrient-poor conditions could be observed. Dominant grass species were *Bromus erectus* and *Briza media*, typical herbs were *Galium verum, Trifolium campestre* and *Pimpinella saxifraga*. Later also *Dianthus armeria, Ranunculus bulbosus, Saxifraga granulata* and *Dactylorhiza majalis* appeared.

The examples show that it is possible to re-establish semi-natural grassland on former arable land. However, the success depends on several preconditions. In this case regional species-rich hay was available. Furthermore, dependent on the nutrient status of the soil and aspired habitat type not everything is possible in a short time. The biological activity of the soil may demand a long time of recovery or it may be even impossible to re-establish adequate soil conditions. The appearance of orchids, for example, normally takes more time than the appearance of common meadow species. However, some species do not appear at all (Jongepierová et al. 2019).

7.3.4 The Meaning of Grassland for Agriculture

For the survival of the diversity of grassland types in Europe grazing and mowing are essential. The meaning of species-rich hay for animal health is hardly compensable by concentrated feed plus pharmaceutical products. If product quality not only means energy equivalents but may also be seen in species-rich hay and production of healthy milk then grassland would not only be a matter of backward oriented nature conservation policies. However, the European policy is the key factor for the determination of such values and the relating payments.

Clearly, the scientific fields of ecology, phytosociology, agriculture, veterinary medicine, and political economy might work more intensively and closely together.

8 Outlook

Fragmentation of grasslands, nomadism and transhumance can hardly be re-organized without plausible and increasing payments for shepherds and farmers.

The market of legal hunting and poaching is highly profitable. Thus, it will be difficult to limit or reduce hunting of wild animals without much stronger regulations and efforts in education including lessons in biodiversity conservation.

On the other hand the global range of nature reserves is still continuously increasing and the realization of the goal to protect 10% of the range of each habitat type is approaching. Goods and services provided by grassland are more and more appreciated. There is an awesome agreement at global scales to protect threatened and rare species from extinction.

What can be done under these circumstances? What should be done? What is realistic?

As the tendencies and examples illustrated here show humans are willing to invest much effort and money to facilitate and promote nature conservation projects, to protect grasslands, to obtain the beauty of landscapes also with respect to their own place identity. Under these preconditions the question arises how money could be invested as effectively as possible.

The exploding amount of scientific information and communication, e.g. possibilities of remote sensing, increased and will increase the attention of positive and negative processes and events.

In general, farmers are not only interested in profit but also in the health and welfare of their livestock and in protecting the sustainable use of their surroundings.

These preconditions might be respected by national and supranational authorities while discussing and organizing policies. Ultimately, the official policy and neither consumers nor single farmers or hunters by their own will decide about the development and survival of the quantity and quality of grassland habitats.

For the survival of grassland ecosystems and zero species loss of grassland inhabitants minimum requirements may be the limitation of further conversion to other habitat types such as arable or urban land, no use of pesticides and no or only moderate application of water and fertilizers. Moderate mowing and pastoralism with low densities of livestock must not harm the ecosystem and should be possible in many regions.

Hunting must be controlled along strong regulations. Scientific irrationalities such as the trade with horns of ungulates for the production of putative medicine and aphrodisiacs should be elucidated by education in public schools. Another possibility may be to overwhelm the market by horns produced in animal farms.

The existing natural, semi-natural and species-rich high-nature value (HNV) grasslands have to be maintained with respect to national and international regulations. Buffer zones against chemical components such as nutrients and pesticides have to be established to reach this goal. Only no further loss is acceptable. The well-maintained grasslands which still exist in Europe, and are managed in a sustainable way should be preserved as a cultural heritage. The survived traditional rural cultures and traditional farming based on local ecological knowledge should be supported and used as a source of knowledge in developing modern biodiversity conservation programmes.

Under certain conditions it is possible to restore destroyed assemblies, e.g. if regional species-rich hay as donator for seeds can be used. However, often the results are questionable, and it is more reasonable to maintain the still existing grassland and pay for their traditional use. The subsidy system should be carefully set clearly differentiating regions with maintained traditional ecological knowledge, where the farmers know precisely how to manage their grassland in a sustainable way, and regions with extinct traditional ecological knowledge, where a sustainable grassland management should be properly examined before any of the measures is subsidized.

Education at public schools, information via media and eco-tourism may be important stepping stones in the policy and planning of grassland conservation. The curricula may include contradictions such as two-dimensional learning (desk, paper, computer) vs. three-dimensional learning (practice in horticulture, excursion), monoculture (plantation) vs. polyculture (grassland), high-nature-value grassland vs. high-productivity grassland (industrial farming).

The goal and agreement is already set with the CBD. However, adequate applications, policies and payments are still missing.

A subsidy system has to be established which guarantees the survival of the existing habitat types including all characteristic rare, endemic and threatened species.

One of the most important practical aspect is the payment for farmers, shepherds and other people who are able to use the system in a sustainable manner.

Development of local markets and product-based subsidies taking into account local conditions are probably the most efficient ways of support for sustainable farming and biodiversity maintenance. The farmers could simply be paid for the occurrence of target-species and target-habitats.

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Heathland, Scrub and Savanna: Overview, Recent Trends and Outlook

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Abstract This contribution provides an overview of the ecology and distribution of the various habitat types which are dominated by small and intermediate-sized woody plants.

Compared to other ecosystem types such as forest or freshwater ecosystems, heaths and scrub have only fairly recently become a central theme of ecological and biogeographical research, and have only been the subject of comparatively few studies to date. Furthermore, these habitats cover only a small proportion of land compared, for example, with forest and grassland. In contrast to the amount of research, and despite the small area of land they cover, these habitats are rich in species and endemics.

Heathland, scrub and savanna comprise a variety of different habitat types and are found from polar regions to the tropics, and from oceanic to continental zones. In general, they occur as transition zones between open landscapes and forest or form a late succession stage in regions with environmental conditions that are unfavourable for tree growth.

Heathlands, especially in Europe, are often the result of long-term anthropogenic influence. Savannas can be found in subtropical and tropical regions and are characterised by a combination of tree and herbaceous species. Both heathlands and savanna provide habitat for many rare, threatened and endemic animals.

The degree of degradation and fragmentation of these habitats varies considerably. Urbanisation, the intensification of agriculture and exploitation for natural resources are the main threats to heath, scrub and savanna worldwide. As the usage of European heathlands for anthropogenic purposes decreases, succession results, thus leading to a reduction in the total area covered by this habitat type.

It is difficult to predict what these very dynamic ecosystems will look like in the future. However, the relatively high number of different habitat types, structures, and species highlights the importance of conservation planning and management of these habitats.

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It generally takes less time to re-establish dwarf shrub or shrub communities than it does for a forest to grow old. This fact can also be seen as an opportunity, especially if rare or threatened species can live in both shrubland and forest.

Keywords Heathland · Savanna · Shrubland · Threats to biodiversity · Future perspectives

1 Introduction: Classification and Terminology

Heathland and shrub habitats include all ecosystems dominated by shrubs and small trees (Davies et al. 2004; Specht 1979a). The maximum height of the vegetation is usually defined as 5 m. The vegetation carpet is open, and many grasses, herbs and mosses can be found. In many regions, such habitats are influenced to a greater or lesser degree by anthropogenic activity. Heathlands and shrubs are often successional stages and can develop e.g. from forests and woodlands or grassland (Hobohm 2014). Under environmental conditions which are not favourable for the growth of trees this habitat type can also occur naturally and remain for long periods of time in the same place.

Heathlands are characterized by short perennial ericoid plants on nutrient-poor soils (Specht 1979a, b).

The term *scrub* comprises different ecosystem types, all of which are characterised by the presence of small, woody perennial plants (Weber 2008). A number of terms such as savanna, heathland, shrubland or others are used in different parts of the world to describe these types of ecosystems; many of these terms are not explicitly distinct from one another and can be used for the same entity. Table 1 gives some definitions or descriptions as used in the literature.

Compared to other habitat types such as forest or freshwater ecosystems, heath and scrub have only fairly recently become a central theme of ecological and biogeographical research, and have only been the subject of comparatively few studies to date. Furthermore, the area covered by these habitats is only small compared to that covered by forest and grassland. Although not well studied, and despite the small area they cover, these habitats are very rich in species and endemics.

The structure of savanna ecosystems is characterised by a combination of single trees or groups of woody plants together with more open land dominated by grasses and herbs. Such ecosystems are found in particular in tropical and subtropical zones. Savannas occupy one fifth of the global land surface (Sankaran et al. 2010). Africa has the most well known savanna, but savannas also exist in South America, Southeast Asia and Australia (Pfadenhauer and Klötzli 2013), and often represent a transition zone between woodland and grassland. One common characteristic of savannas under the otherwise different climatic conditions is the seasonal rainfall (Solbrig et al. 1996). The term *savanna* originates from a native American language (Marchant 2010) and designates a landscape that can harbour a variety of

Table 1 Terms used for woody vegetation units of small and intermediate height

Habitat	Definition	References
Heath	Evergreen ericaceous dwarf shrub vegetation on nutrient- poor soil, for example in temperate regions of Europe. Mediterranean heaths are often dominated by larger shrubs such as *Cistus* spp.	Specht (1979a, b), Janssen et al. (2016)
Scrub	Vegetation type dominated by woody shrubs, often of varying height and structure	Weber (2008)
Shrubland	Vegetation dominated by woody shrubs mixed with grasses and herbaceous plants on different soils	Weber (2008)
Savanna	A combination of a discontinuous tree layer and a continuous layer dominated by grasses and/or herbs. This term is rarely used in Europe even if related vegetation units exist (e.g. dehesa)	Foxcroft and Richardson (2010), Joffre et al. (1999)
Chaparral	Evergreen shrub formation of SW North America	Hanes (1981)
Garrigue	Evergreen sclerophyllous low shrubs of the Mediterranean area forming an open canopy structure	Davies et al. (2004)
Macchia	Evergreen sclerophyllous shrubs of the Mediterranean area forming a closed canopy structure	Davies et al. (2004)
Mallee	"Is a colloquial name that is used to describe species of *Eucalyptus* that have a low shrubby growth form"	Menkhorst and Bennett (1989, p 39)
Kwongan	Sclerophyllous shrub vegetation of Australia	Rea et al. (2011)
Matorral	Sclerophyllous shrub vegetation of Chile	Fuentes et al. (1986)
Cerrado	Biome in S America including various types of grassland, savanna and woodland	Ratter et al. (1997)
Fynbos	Heathland of South Africa	Kruger (1979)

ecosystems. Grazing by wild and domestic animals, fire, and in some regions the direct influence of man form the landscape of the savanna and in some cases limit succession to woodland.

For a long time, transition zones in space and intermediate succession stages, especially shrub and fringe habitats, were disregarded in science. Today, however, the value of these habitats is more widely appreciated. Scrub and heaths are recognized as distinct and ecologically specialised ecosystems, often representing a transition zone or succession stage, which thus play an important role in the networking of different ecosystems (Rego et al. 2013). The habitat degradation and loss which have occurred in the last decade highlight the importance of protecting and restoring these habitats (Fagundez 2013).

Scrubs and heaths can be found all over the world, from polar regions to tropical regions (Specht 1979a, b); they often occupy only small areas and show great diversity from one region to another.

2 Heathland, Shrub and Savanna Habitats Around the World

Around the world, each region harbors a great variety of shrub, heathland and/or savanna habitats with a unique and characteristic species composition. The following examples provide an overview of the variety of these habitats, their ecological conditions and threats. They are intended to highlight the importance of protecting and managing these ecosystems.

2.1 Europe

Across Europe, most heathlands and shrub habitats are manmade and influenced by activities, such as grazing, fire, and felling of trees for timber, that open up the landscape (Gimingham et al. 1979).

The first occurrence of inland heath dates back to c. 4000 years BP (Webb 1998). Climatic conditions which limit the growth of trees favour the development of heathland (Heil and Aert 1993). This is often the case in alpine zones (Fig. 1), in coastal regions and in the tundra of the arctic region.

Heaths and shrublands are widespread today and can be found from the Arctic to the Mediterranean, and from coastal to eastern continental regions.

Fig. 1 Shrub vegetation in alpine zones of the Austrian Alps (photographed by author)

Table 2 Endangered heath and shrubland habitats of Europe (Janssen et al. 2016; *VU* vulnerable, *EN* endangered)

Code	Habitat type	Red List category EU 28+
F3.1d	Balkan-Anatolian submontane genistoid scrub	VU
F4.1	Wet heath	VU
F4.2	Dry heath	VU
F5.5	Thermomediterranean scrub	VU
F8.1	Canarian xerophytic scrub	VU
F8.2	Madeiran xerophytic scrub	EN

Fig. 2 Dry heathland dominated by *Calluna vulgaris* in N Germany (photographed by the author)

The European Red List of Habitats describes 40 different habitat types of heathlands and shrubs. It also classifies the degree of endangerment of the different terrestrial and marine habitats and gives an overview of the distribution and endangerment of each habitat type. The heathland and shrub habitats of the Mediterranean, Macaronesaian and Atlantic Regions are very diverse, with 13% of the described habitats classified as vulnerable. These occur in different regions of Europe (Table 2) (Janssen et al. 2016).

An example of a vulnerable habitat is dry heath (F4.2) (Fig. 2), one of the most important and widespread heathland habitats in Western Europe with a current estimated total area of 25,822 km^2 (Janssen et al. 2016), a high proportion of which is of anthropogenic origin. This habitat hosts a great diversity of invertebrates, including numerous species of insects (Webb and Hopkins 1984; Schirmel et al. 2010).

The Madeiran xerophytic scrub (F8.2) is classified as endangered. Succulent plant species, many of them endemic, form this habitat. The current estimated total area of this scrub habitat is only 2 km^2 (Janssen et al. 2016).

The subalpine *Pinus mugo* scrub F2.4 is an example of a natural transitional shrub habitat type. This shrub type can be found in the mountains of central and south-eastern Europe (Janssen et al. 2016). Above the timberline, *Pinus mugo* forms dwarf shrubs (Sibik et al. 2010), which mark the transition zone between the forest and the alpine vegetation (Zeidler et al. 2012).

Another habitat type, the shrub tundra F1.1, occurs under extreme environmental conditions, where cold climate conditions do not allow the growth of trees (Bliss 1979). The shrub tundra is a transition zone between the taiga and the grassland tundra. In Europe, this habitat type can be found in Spitzbergen (Norway), Russia, Iceland and north continental Scandinavia (Davies et al. 2004). This type of shrub harbours many mosses and lichens.

The Macaronesian F4.3 heathlands are unique in terms of species composition. They harbour many threatened and/or endemic plant species (Page 1976).

A variety of ecosystems that belong to heaths and scrub can be found in the Mediterranean regions. Some of these are natural vegetation units but many of them are the result of anthropogenic use and activities where fire, grazing and deforestation have transformed woodlands into a more open landscape with shrubs and grasses. In some regions, these ecosystems are called maquis or macchia. When anthropogenic impact is more intense, they may develop into garrigue with dwarf and spiny shrubs, many annuals and vernal geophytes (Davies et al. 2004). The maquis and garrigue are part of the Mediterranean biome. The Mediterranean shrublands are species-rich (Walter and Breckle 1991) and they harbour many endemic plant species (Hobohm 2014).

Heathland and shrubland in Europe harbour more endemic vascular plants than e.g. woodlands, freshwater habitats or mires (Bruchmann and Hobohm 2010). This shows the importance of protecting and managing such habitats.

2.2 Africa

Africa can be divided in two large biogeographical regions, North Africa and sub-Saharan Africa. As in many other parts of the world, shrublands often represent a transition zone between open landscape units such as desert, semidesert or grassland and woodland or forest (Happold and Lock 2013).

Mediterranean shrub- and heathlands can be found in North Africa (Cowling et al. 1996). They are part of the natural vegetation e.g. above the tree line in the Atlas Mountain. Maquis and garrigue are the result of forest degradation at lower elevations between the Atlas mountain chain and the Mediterranean Sea and these habitats are more or less strongly influenced by humans with their livestock (Quezel 1977; White 1983).

More than half of the area south of the Sahara consists of different types of savannas (Du Toit and Cumming 1999), with broad-leaved savanna in the higher regions and fine-leaved savanna in the lowlands.

The African savannas harbour the highest diversity of ungulate species (Du Toit and Cumming 1999). These animals, some of which are endemics (Turpie and Crowe 1993), control the structure of savannas by grazing and trampling.

The largest and most diverse shrubland in Africa is found in the southwest part of the continent, the Karoo-Namib region (White 1983). Dwarf shrubs and succulents are important components of the Karoo shrublands (White 1983).

The succulent Karoo biome is species-rich, and many species are regional endemics (Mucina et al. 2006). The region harbours about 6356 vascular plant species (Driver et al. 2003).

In the Cape, the heathland is known as fynbos. The species composition of the fynbos, including coastal, arid and mountain fynbos types, can be extremely diverse in the various regions of the Cape (Goldblatt 1978; Rebelo and Siegfried 1990), with some of the richest species pools in the world (Kruger 1979). The fynbos of South Africa is also a habitat for many endemic vertebrates such as the golden mole *Chrysochloris asiatica*, the geometric tortoise *Psammobates geometricus* or Victorin's warbler *Cryptillas victorini* (Bigalke 1979).

In Madagascar, dry spiny bush can be found in the southwest part of the island (Burga 2011). This habitat type is unique in terms of vegetation structure and species composition (White 1983) and many of the plant species and reptiles are endemic to the south of Madagascar (Cabanis et al. 1969). Another type of shrubland, rupicolous shrubland, is found in rocky parts of the island. Some of the mountain heathlands of Madagascar represent secondary vegetation units, which are the result of anthropogenic influence and fires (Raxworthy and Nussbaum 1996).

2.3 North America

The shrubland of the Low Arctic region of North America is dominated by species such as *Betula nana*, *Salix glauca* and *Salix pulchra*. These are often associated with grasses, mosses and Ericaceae (Bliss 1979). Arctic heathlands can be found in Alaska and Canada, where their structure and species composition are similar to those in other parts of the Arctic; they consist mainly of Ericaceae, mosses and lichens (Hanson 1953; Whittaker 1977).

The salt spray heathland, an endangered ecosystem type, is found in the coastal region in the NE of the United States of America. The influence of salt reduces the speed of succession and influences the composition of the vegetation in these heathlands (Griffiths and Orians 2003).

Vast shrublands in the USA can be found in the semi-arid region of the western part of the country (McArthur and Kitchen 2007). Huge areas in the west of the

United States are dominated by sagebrush (*Artemisia* div. sp.), with *Artemisia tridentata* one of the most widespread species (Davies et al. 2011). The relating landscape units cover about 13.3–14.5% of the total shrubland area in the USA (Xian et al. 2015).

The chaparral of California comprises shrublands under the influence of a Mediterranean-type climate. Evergreen shrubs dominate, as in other Mediterranean climate regions (Franklin et al. 2004; Hanes 1981). As part of the Mediterranean biome this habitat is species rich and harbours many endemic plant species (Cowling et al. 1996).

2.4 South America

In most regions of the continent and at all elevations below alpine zones woody vegetation dominated by dwarf shrubs, shrubs or succulents represents transitions between open vegetation and forest in space or time. Despite their species richness, the savannas of South America receive less protection and management than the Amazonian Forest (Ratter et al. 1997).

The Cerrado biome of Brazil covers about 23% of the country. The biome is dominated by grassland, shrubland, woodland, various transition zones, and harbours South America's most species-rich savanna (De Oliveira-Filho et al. 1989; Ratter et al. 1997). Many reptiles and amphibian species are endemic to the Cerrado, which also provides habitat for a great diversity of insect species (Klink and Machado 2005) as well as critically endangered animals such as the blondtiti monkey *Callicebus barbarabrownae* and glaucous macaw *Anodorhynchus glaucus* (IUCN 2019).

The llanos of Columbia and Venezuela (Medina and Silva 1990) represents the second largest savanna habitat of South America (Huber et al. 2006).

In Chile, species-rich evergreen shrubs form the matorral, which is comparable to the chaparral in California (Jaksic and Fuentes 1980; Rundel 1977). This sclerophyllous shrub habitat occurs in a Mediterranean-type climate. As part of the Mediterranean biome the matorral harbours great biodiversity (Cowling et al. 1996).

Some heathland habitat also exists in South America. Wet heathland can be found in Patagonia, where the vegetation is dominated by *Empetrum rubrum* (Moore 1979).

2.5 Oceania

In many regions of Australia climatic conditions and fire favour the development of scrubs, heathlands and transitions to woodland.

The S and W of Australia with winter rain and summer drought is home to one of the most species-rich biomes on Earth (Cowling et al. 1996). Kwongan and mallee are landscape units of South Australia. Kwongan is a vegetation type similar to the maquis in Europe or the chaparral in California. The mallee is an open shrub vegetation, consisting mostly of *Eucalyptus* species growing on oligotrophic soil (Holland 1969; Specht 1979a, b). Many endemic species occur in both habitats. The mallee ecosystem has a diverse reptile fauna. Examples of endemic species are the mallee dragon *Ctenophorus fordi* and the southern Mallee ctenotus *Ctenotus atlas* (Menkhorst and Bennett 1989). The mallee is also the habitat of more than 100 species of birds. The red-lored whistler *Pachycephala rufogularis* and black-eared miner *Manorina melanotis*, for example, are among the birds which are restricted to this ecosystem (Schodde 1981; Keith et al. 2014).

Heathlands can be found in New Zealand. In the north of New Zealand, most heathlands are the result of deforestation (Enright 1989). Both the North and the South Island are covered partially by different types of heathland. Some are the result of anthropogenic influence and others are the result of specific environmental conditions (Burrows et al. 1979).

2.6 Asia

Asia harbours a great diversity of shrub ecosystems which all differ from those in Europe. The different habitats often merge directly into one another, with savannas and shrublands often forming a transitional stage between grassland and forest. In many cases, the savannas of Asia are not considered distinct ecosystems and are classified as degraded forest (Ratnam et al. 2016). Deciduous broadleaf savanna, fine-leafed spiny savanna and pine savanna are all found in continental regions of SE Asia (Ratnam et al. 2016). Like the savannas in Africa they provide habitat for endemic ruminant mammals, among them many rare species, such as the critically endangered kouprey *Bos sauveli*. A couple of years ago there have been only 50 individuals of this species left and the probability that this animal is already extinct is high (Timmins et al. 2016).

In Malesia, natural heathlands can be found on nutrient-poor sandy soil or above the timberline. At lower elevations, forests and heathland are not clearly delineated. In some cases, heathland species and trees coexist and form heath-forest (Specht and Womersley 1979).

The Thar Desert is a thorny shrubland in Rajasthan India (Bhandari 2005). Many endemic and rare species live in this ecosystem (Khan 1997) making it a regionally important and highly biodiverse habitat.

A high diversity of plant species is also found in the alpine shrub vegetation of the Himalaya Mountains (Chawla et al. 2008).

The arid climatic conditions of Afghanistan favour the growth of shrubland. A great variety of shrub vegetation, such as juniperus shrubland, subtropical dry scrub, and the Rhododendron-Krummholz of the higher-altitude mountain areas, is to be found in the various regions of the country (Breckle 2007).

3 Degradation and Threats to Heathland, Shrub and Savanna Habitats

The large number of critically endangered species in heath, shrubland and savanna highlight how important it is to protect and preserve these habitats.

According to the IUCN Red List, shrublands worldwide harbour 293 animal and 333 plant species that are classified as critically endangered. Savannas are the habitats of 62 critically endangered plants and 39 critically endangered animal species (IUCN 2019; assessed 6/2019). Both vertebrates and numerous invertebrates are among the critically endangered animals of these habitats.

Figures 3 and 4 show the numbers of critically endangered species that inhabit shrublands and/or savannas in different parts of the world. In the following, some examples of critically endangered animals and plant species are given to highlight the importance of these habitats for nature conservation.

An example of a critically endangered vertebrate species which is only known to exist in the shrubland of an Andean valley in Ecuador, is a reptile called Peters ameiva *Holcosus orcesi*. The number of adult individuals is unknown and the likelihood of this animal already being extinct is high (Cisneros-Heredia et al. 2017).

Another critically endangered animal species is the giant lizard *Gallotia bravoana* which inhabits shrublands on La Gomera, Canary Islands. This endemic reptile can only be found in two localities on the island. The wild population is estimated to consist of 90 individuals (Miras et al. 2009).

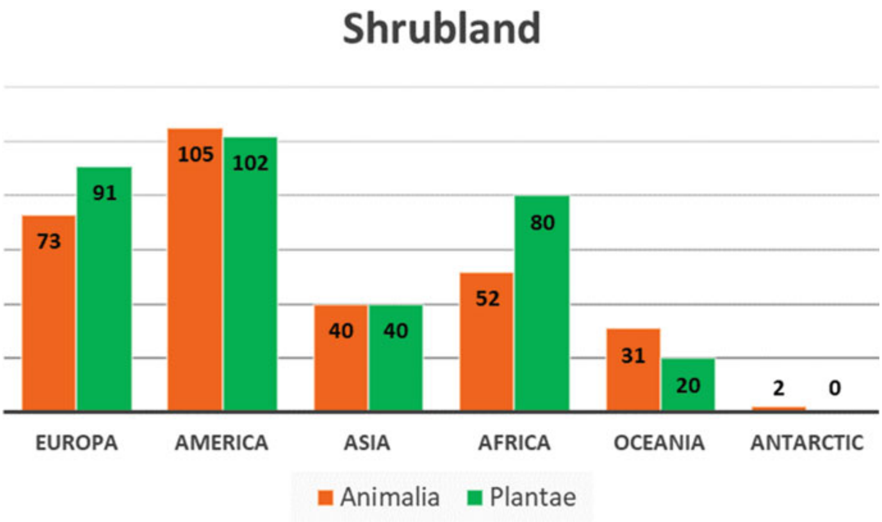

Fig. 3 Number of critically endangered species (CR) in shrublands of the various continental regions (IUCN Red List: https://www.iucnredlist.org/ 11.01.2019, illustration created by the author)

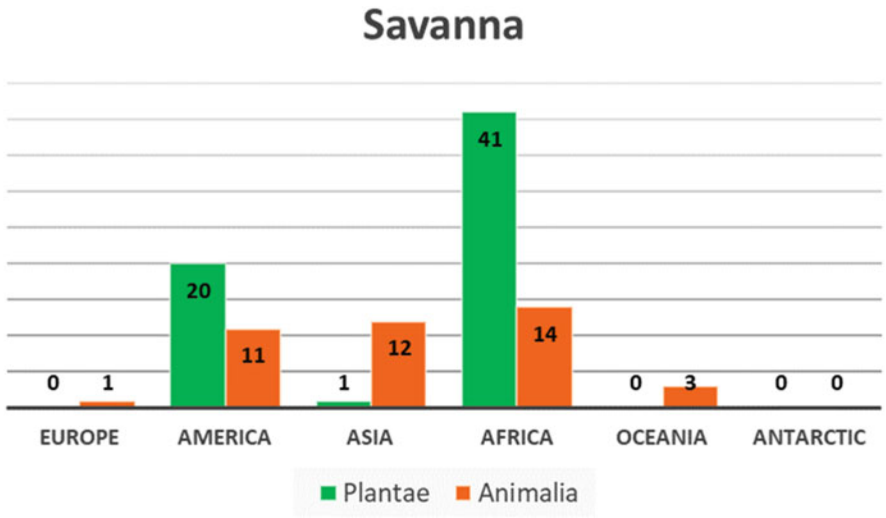

Fig. 4 Number of critically endangered species (CR) in savannas of the various continental regions (IUCN Red List: https://www.iucnredlist.org/ 11.01.2019, illustration created by the author)

The dwarf ebony *Trochetiopsis ebenus* is also considered critically endangered. This plant can be found in shrubland on Saint Helena, where only two adult individuals now remain (Lambdon and Ellick 2016).

Orthotrichum handiense is an example of a critically endangered bryophyte species. This species is endemic to the Canary Islands and the existing 50 individuals can be found only at a single location in the shrubland of Fuerteventura (Mancebo et al. 2019).

The northern hairy nosed wombat *Lasiorhinus krefftii* inhabits the savanna of Australia. The population of this critically endangered species has been estimated to consist of only c. 113 individuals (Sam et al. 2003).

Examples of critically endangered plants that can be found in savannas are: *Uebelmannia buiningii* (Brazil), *Turraea elephantina* (Kenya) and *Linderniella boutiqueana* (Burundi) (IUCN 2019).

There are many reasons for the loss and degradation of habitat around the globe. In Brazil, for example, a large area of the Cerrados has been transformed into agricultural land (Ratter et al. 1997). In South Africa, the area covered by fynbos is decreasing. Agriculture and urbanisation had already destroyed 48% of the dune asteraceous fynbos and 77% of the sandplain proteoid fynbos of the cape of Peninsula by the end of the last millenium (Richardson et al. 1995).

In Europe, most of the heathlands and shrubs are manmade and at risk due to abandonment, as this favours the growth of forests.

13% of the heathlands and shrubs described in the European Red List of Habitats (Janssen et al. 2016) are vulnerable, and a decrease in heathland areas can be observed almost everywhere in Europe. For example, 99% of Belgium's heathland areas have disappeared since 1775 (Piessens and Hermy 2006). Heathlands in

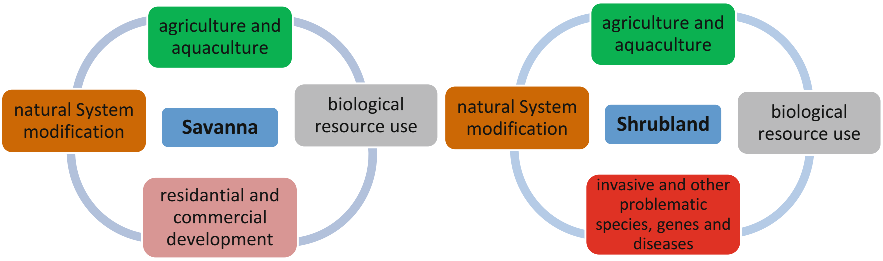

Fig. 5 Main threats to critically endangered savanna and shrubland species (IUCN 2019, illustration created by the author)

Europe today are fragmented, isolated and often surrounded by agricultural land (Webb 1998).

In Australia 30% of the heathlands are now serve other land use purposes (Keith et al. 2014).

Savanna and shrubland face similar threats globally (Tscharntke et al. 2005; Mckinney 2002; Richardson et al. 1995). According to the (IUCN 2019, assessed 6/2019), the main threats to critically endangered shrubland species are agriculture and aquaculture, natural system modifications, invasive and other problematic species and biological resource use (Fig. 5). Critically endangered savanna species are also primarily threatened by agriculture and aquaculture, biological resource use and natural system modification, but residential and commercial development poses an additional threat here (Fig. 5).

A worldwide loss of ecosystem biodiversity due to the increase of urbanisation and agricultural land can be observed. The expansion and intensification of agriculture is one of the most significant reasons for the transformation of land (Lambin and Meyfroidt 2010) and the most important factor in the loss of habitats. In the different continental regions, agriculture is a major threat to the critically endangered animals and plants occurring in shrubland and savanna habitats (Figs. 6 and 7). Globally, the expansion of small farms has a stronger impact than the agroindustry, as 90% of the farms are smaller than 2 ha (Tscharntkea et al. 2012). Not only crop and timber plantation but also grazing can be a threat to the biodiversity of these habitats. Overgrazing can cause the degradation of woody vegetation units leading to a downscaling of the vegetation structures and altering species composition. In many regions of Asia and Africa, domestic animals displace wild herbivores in grasslands and savannas (Du Toit and Cumming 1999).

Urbanisation endangers the diversity of habitats and can lead to biotic homogenisation (Concepción et al. 2015). Urbanisation and agriculture expansion lead to the fragmentation of shrublands and savannas. This, in turn, reduces the exchange between populations, thus reducing species diversity, even if the environmental conditions within the habitats are still adequate (Andren 1997).

Biological resource use, such as hunting and collection of plant material can also cause degradation of savanna and shrubland habitats. Gathering of terrestrial plants,

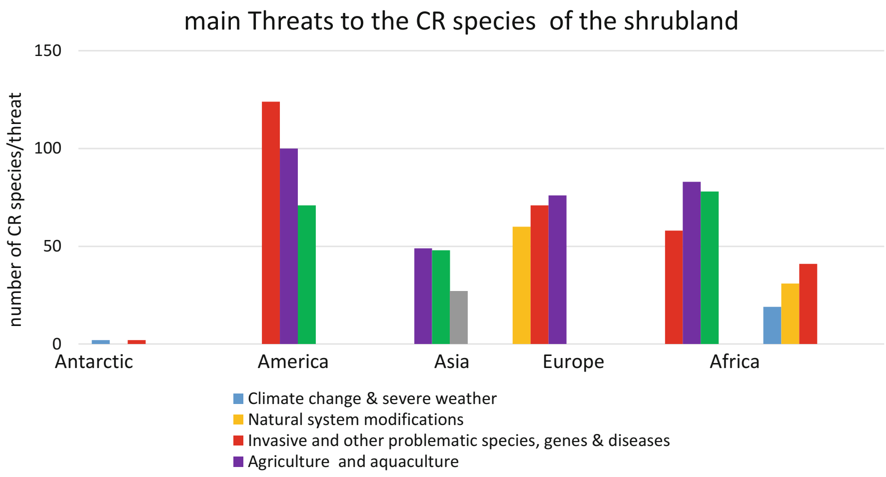

Fig. 6 Main threats to the critically endangered plant and animal species of the shrublands (IUCN Red List: https://www.iucnredlist.org/ 06.2019, Illustration created by the author)

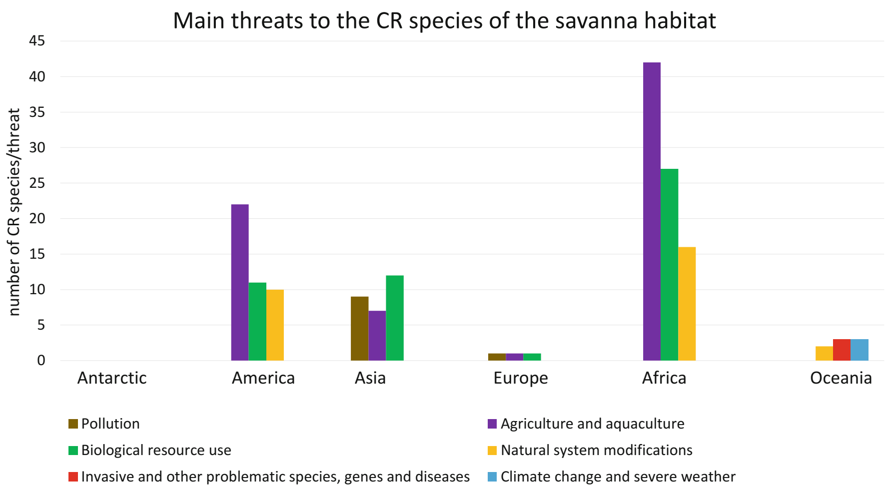

Fig. 7 Main threats to the critically endangered plant and animal species of the savannas (IUCN Red List: https://www.iucnredlist.org/ 06.2019, illustration created by the author)

logging and wood harvesting are threats to the vegetation diversity of the savannas and heathlands in several parts of the world (Figs. 6 and 7).

Natural system modifications such as fire and fire suppression and the invasion of native and alien species are non-negligible threats to species living in heath, shrubland and savanna habitats (Figs. 6 and 7).

Fires are an important factor. Depending on the regional frequency and seasonality of natural fires, the effect can be stabilisation of or damage to the natural species composition (Glitzenstein et al. 1995). The suppression of fires in many regions of the world can have dramatic effects on natural species composition.

4 Conclusion and Outlook

Scientific awareness of habitats dominated by dwarf shrubs or shrubs is not as advanced as for forest, freshwater ecosystems, or coastal habitats, for example. In comparison with forest or wetland areas, heath and shrub habitats have received little attention in ecological research and practical nature conservation programmes.

This group of habitats harbours a huge diversity of plant and animal species with many endangered species. In most cases, they represent transitions between open landscapes and forest in space or time or are composed of different structural elements and vegetation heights. The vegetation structure of these woody habitats is often much richer than that of neighbouring habitat types.

In some cases, shrublands can provide alternative habitats for forest or grassland species if these habitats in the neighbourhood are destroyed.

Thus, increased appreciation of these types of landscapes and habitats in science and nature conservation practice might help to find solutions for protecting the natural biodiversity.

Appreciation can mean, for example, recognition, mapping, and protection of the respective habitat types.

Large areas of arable land where woody structures have already been completely destroyed might be given more value allowing space for small strips along the fields for natural succession or establishment of hedgerows, for example.

The heathlands, shrublands and savannas of the world include unique and diverse ecosystems; these habitats harbour many rare and endemic plants and animals. However, loss and degradation of heathlands, savannas and shrublands can be observed worldwide, in both developing and industrial countries.

Many heathlands have soils with low or very low nutrient contents. It is not easy to protect oligotrophic conditions in regions with an input of eutrophic substances such as NO_x from the atmosphere or agriculture. However, different courses of action have been successfully tested to protect heathland in many regions of Europe.

The savannas also face many environmental and conservation problems. Desertification is often the result of intensive grazing and too many domestic animals (Sivakumar 2007), leading to a decrease in woody plant cover, as for example in West Africa (Thiollay 2006). Most likely, some savannas will continue to degrade and will transform into deserts.

Changing use intensities and global warming result in a shift of vegetation zones and change of distribution patterns, and a migration of scrub zones to the North can already be observed (Tape et al. 2012). If temperatures continue to rise, subarctic shrubs and heaths may immigrate into areas where conditions were previously unsuitable. In the United States of America, for example, shrubs are encroaching into the prairie, due to changes in land use. A savanna-like ecosystem with a mixture of grasses and shrubs has developed here (Briggs et al. 2005).

With the growth of population in Asia and Africa, urbanisation is increasing (Boadi et al. 2005). If this trend continues, many ecosystems will be affected due to the expansion of cities.

Both native and alien invasive species can cause problems for rare, threatened and endemic plant and animal species. Islands in particular seem to be sensitive to this problem (Reaser et al. 2007). It is possible that the dispersal of invasive species also influences the distribution of heathlands and shrubs. In Western Europe, native and non-native tree species can occupy the coastal heathlands and change the characteristics of a whole ecosystem (Saure et al. 2014). However, these invasions are often accompanied by changes in or abandonment of traditional use.

Fertilization often causes the extinction of plant species and the related food webs which are adapted to nutrient-poor conditions. This is the case in many European heathlands. The higher availability of nitrogen associated with the abandonment of traditional use results in the decrease of ericoid shrubs and the propagation of grass species (Terry et al. 2004). The higher nitrogen availability in heathlands can lead to nitrogen-limited plant growth becoming phosphorus limited (Haerdtle et al. 2009). Changes in nutrient availability should be taken into consideration in future management of heathlands, as different management practices affect the availability of nutrients in the ecosystem (Diemont et al. 2013).

To preserve the biodiversity in these habitats, a number of protection and conservation measures need to be taken.

This goal cannot be achieved by protecting only small, fragmented areas. In Africa, the protected areas are insufficient to assure the survival of many endemic animal species, as many of these species are migrants (Western and Ssemakula 1981). The management of non-protected areas can play an important role in the conservation of the savanna habitat and its endemic species. This is, for example, the case in Kenya's Pro-wildlife ranges where wildlife conservation and extensive cattle grazing coexist (Georgiadis et al. 2007).

In many developing countries poverty and the lack of resources can lead to further degradation of the ecosystems. The savannas and shrublands of developing countries can be affected by this problem. In some cases, this is described as a "downward spiral": poverty, the overuse of resources and environment degradation influence each other (Scherr 2000). Poverty reduction, better management of resources and environment education can help to preserve the diversity of ecosystems.

In Europe, fragmentation and rapid decline of heathland areas can be observed, and effective management is needed to maintain the last intact areas. The actions needed depend on the area. In many cases, characteristic heathland has been successfully restored by removing vegetation and the fertilized top soil, with heathland occurring again after a couple of years of succession. In Dorset, UK, for example, a variety of management actions were applied to restore heathland from pioneer succession (Mitchell et al. 1999). A sustainable use of the habitat, such as sustainable honey, meat and wool production, might be a solution. The management actions required depend strongly on the specific ecosystem.

There is major debate on whether humans should manage the ecosystems or not. Without the intervention of humans, succession would in many cases result in woodland with lower species diversity (Maher et al. 2010). A mosaic of different habitat types composed of half-open landscapes might be most successful with respect to the conservation of high biodiversity. The conservation and management of heathlands, savannas and shrubs should be considered a priority because these landscapes are highly biodiverse and provide habitat for many endemic species.

Similar problems and threats seem to endanger the biodiversity of these habitats all over the world.

The future of heathlands, savannas and shrublands is difficult to predict. They are very dynamic ecosystems so it is possible that in some place these habitats will disappear, and with them many plants and animals. The large number of critically endangered species that live in shrublands and savannas highlights the importance of these habitats. However, they require not only protection but also management.

A mosaic of different ecosystems, which must include heathlands, savannas and shrubland, is important to assure high biodiversity.

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Forest Ecosystems: A Functional and Biodiversity Perspective

Andreas Fichtner and Werner Härdtle

Abstract This chapter provides an introduction to the biodiversity of forest ecosystems and highlights the currently acting drivers of forest biodiversity loss. Recent findings on relationships between biodiversity patterns and ecosystem functions are summarized, including the functional consequences of biodiversity loss for the stable provision of forest ecosystem services. Finally, implications for the protection and management of forest ecosystems as important means for biodiversity conservation and climate change mitigation are addressed.

Forest ecosystems host a huge proportion of the Earth's terrestrial biodiversity and play a crucial role in global biogeochemical cycles. However, dramatic losses of forest area currently constitute an important driver of global biodiversity loss, with unprecedented consequences for the functioning of forest ecosystems and the services they provide. This applies to tropical rain forests in particular, which are estimated to support about two-thirds of the global biodiversity, despite covering less than 15% of the world's land surface. For the years 1990–2005, the net loss of natural tropical forest area was estimated to 135 million hectares. As a consequence of losses of forest area, more than 5000 tree species from 180 countries are currently threatened with extinction. Declining forest area and associated biodiversity loss in turn will feedback on important functions of forest ecosystems. Declining forest area (in the decade 2003–2012) generated a mean biophysical warming on land corresponding to about 18% of the global biogeochemical signal due to CO_2 emission from land-use change. Primary producer diversity, for example of tree species, enhances forest productivity due to resource partitioning, facilitation, natural enemy partitioning or selection effects. As a consequence, maintaining tree diversity is an important prerequisite for both the long-term preservation of ecosystem functioning and the provision of ecosystem services such as timber production or climate change mitigation. It is assumed that a 10% decline of tree species richness will result in a 2–3% reduction of forest productivity at the global scale. The monetary value of tree species richness in maintaining commercial forest

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productivity is estimated to amount to $166 to $490 billion per year, highlighting the functional importance of forest biodiversity and the need for safeguarding forest biodiversity for human well-being.

Besides the establishment of extensive protected forest areas (wilderness areas) across forest biomes, forest management is considered an important tool for the preservation of biodiversity and ecosystem functioning, as key attributes for forest species conservation and ecological processes critically depend on management intensity. Therefore, sustainable forest management strategies (i.e. ecosystem-based approaches) across forest biomes are required that (1) avoid deforestation and land-use changes, (2) approach key attributes of 'natural forest communities' (e.g. biome-specific tree species composition and diversity), (3) allow for and maximize the natural dynamics typical of the respective forest ecosystems, and (4) prioritize the minimization of silvicultural interventions over the maximization of forest timber exploitation, thus optimizing biodiversity protection and forest ecosystem functioning (including ecosystem resistance and resilience against global change). Moreover, we highlight the importance of ecological continuity for safeguarding forest biodiversity and its functional role in mediating the response of forest ecosystems to multiple environmental changes.

Keywords Biodiversity · Global change · Climate change mitigation · Ecosystem functioning · Ecosystem multifunctionality · Forest management · Land-use change

1 Introduction: Forest Biodiversity Loss und Human Well-Being

Forest ecosystems host a huge proportion of the world's terrestrial biodiversity and play a vital role in providing benefits for human well-being (ecosystem services), such as climate and water regulation or wood production (MEA 2005). However, species go extinct at an alarming rate due to human-induced changes of the environment (Butchart et al. 2010; Ceballos and Ehrlich 2018), and ongoing biodiversity loss is expected to critically alter the functioning of ecosystems, thus diminishing the benefits that people obtain from forests (Loreau et al. 2001; Cardinale et al. 2012; Isbell et al. 2017). For example, anthropogenic drivers of environmental change (i.e. people's actions that have long-lasting impacts on biodiversity, species composition and ecosystem functioning) can alter forest ecosystem functioning and the related ecosystem services either directly by changing species' metabolism and demography or indirectly by altering communities' functional composition and diversity (Díaz et al. 2007; De Laender et al. 2016; Zhang et al. 2018). The reliable provisioning of ecosystem services therefore requires a social-ecological perspective that accounts for the complex interdependence between human-induced changes of the environment, ecosystem integrity and human well-being (Fig. 1). Hence,

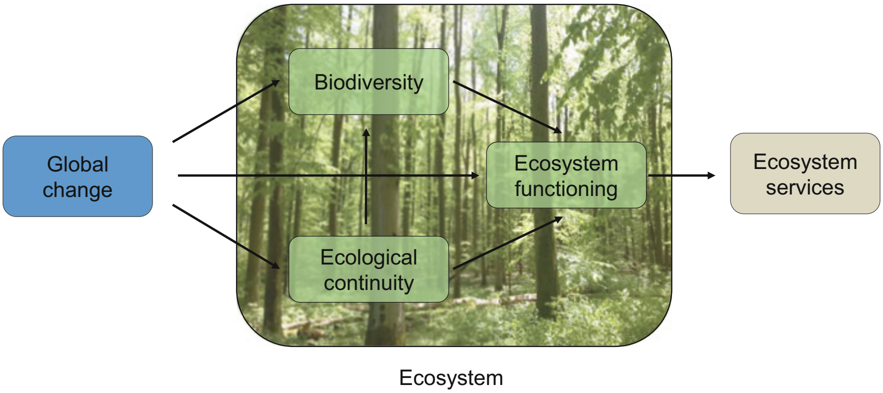

Fig. 1 Human dependence on nature. Global environmental change induced by people's actions, such as land-use change and climate change, can affect ecosystem functions directly or indirectly via altering biodiversity and/or ecological continuity (biodiversity-mediated and/or ecological continuity-mediated response). Alternatively, biodiversity and ecological continuity jointly drive ecosystem functioning, and thereby regulating indirectly the benefits that nature provides to people (ecosystem services). Disruption of ecological continuity due to land-use change or land-use intensification can also translate into biodiversity loss, which in turn can negatively affect the functioning of ecosystems

safeguarding biodiversity is increasingly becoming a vital societal task in the context of global environmental change (Griggs et al. 2013).

This publication provides an introduction to the biodiversity typical of the world's most important forest biomes (i.e. tropical, subtropical, temperate, and boreal forests) and highlights the currently acting drivers of forest biodiversity loss. The most recent findings on relationships between biodiversity patterns and ecosystem functions in forest ecosystems will be summarized, including the consequences of biodiversity loss for the provision of important ecosystem services. Finally, this chapter highlights the implications for the protection and management of forest ecosystems as important means for biodiversity protection, climate change mitigation and meeting global environmental agreements.

2 Distribution and Ecological Characteristics of Important Forest Biomes

Forest ecosystems cover about 4356 million ha (equaling about 30%) of the earth's terrestrial surface (in the 2005), with major areas in Asia (8.9%), Europe (6.9%), North and Central America (6.2%), South America (6.1%) and Africa (4.5%); according to data from MEA (2005), FAO (2015), Keenan et al. (2015). Among forest biomes, tropical forests occupy by far the largest forest area (2027 million ha, 13.6% of the earth's terrestrial surface; Table 1), followed by boreal forest

Table 1 Total forest area, productivity, carbon stocks, forest area losses and protected forest area across different forest biomes (data were compiled from MEA 2005; Keeling and Phillips 2007; Pan et al. 2011; FAO 2015; Keenan et al. 2015)

Biome	Total area (million ha in 2005)	Percentage (%) of total landsurface (2005)	Net primary productivity (Mg ha^{-1} year^{-1})	Carbon stock (Pg in 2007)	Carbon density (Mg ha^{-1} in 2007)	Area change (million ha from 1990 to 2005)
Boreal forests	1258	8.4	c. 7	271.5	239.2	−1
Temperate forests	697	4.7	c. 13	118.6	154.7	+41
Subtropical forests	353	2.4	c. 22	No data available	No data available	−1
Tropical forests	2027	13.6	c. 25	471.0	241.6	−135
Total	4356[a]	c. 30		c. 861[b]	c. 198[b]	−96

[a]Including all forest biomes (i.e. such as the polar region)
[b]According to data from Pan et al. (2011)

ecosystems (1258 million ha, 8.4%). Temperate and subtropical forests cover areas of 697 million ha and 353 million ha, respectively, which equals 4.7% and 2.4% of the earth's terrestrial surface (these data are in good agreement with other forest area estimates, e.g. provided by the FAO 2015; note that differences in forest area may be related to methodological differences in forest area detection and assessments).

The most distinct ecological feature characterizing the different forest biomes are climatic conditions. Tropical forests miss a seasonal, but often show a clear diurnal climate, with day-night differences of 6–11 °C and daily mean temperatures of about 25 °C and. Annual rainfall is equally distributed across the year, and annual precipitation is about 2000–3000 mm (tropical rainforests). Sub-tropical forests, in contrast, are characterized by a shift between monsoon and dry seasons, with an annual precipitation ranging between 1500 and 2000 mm and annual mean temperatures of c. 18–19 °C. Temperate and boreal forests show annual precipitation rates of 500–1000 mm and 400–500 mm, respectively, with annual mean temperatures of 8–14 °C and 6–8 °C.

Related to differences in climate, particularly growing season length, forest biomes exhibit specific patterns in their aboveground net primary productivity (NPP). Tropical (rain) forests show the highest NPP (about 25 Mg ha^{-1} year^{-1}), followed by (sub-)tropical (seasonal) and temperate forests ecosystems (22 Mg ha^{-1} year^{-1} and 13 Mg ha^{-1} year^{-1}, respectively; Keeling and Phillips 2007). Boreal forests have a mean NPP of about 7 Mg ha^{-1} year^{-1}, and hence the lowest productivity across forest biomes.

Importantly, both NPP and biomass levels are valuable indicators of the potential of forest ecosystems to provide various services such as timber production and carbon storage (MEA 2005). Forest NPP and forest biomass, however, often are poorly correlated (Keeling and Phillips 2007), making it difficult to infer forest biomass levels from NPP values. Boreal forests, for example, constitute important carbon sinks and thus are considered vital for climate change mitigation, despite their low productivity. Particularly soils of boreal forests are characterized by the highest carbon stocks across forest biomes: In boreal forests, 60% of the total carbon is stored in soils and only 20% in biomass, whereas in tropical forests 56% of the ecosystem's carbon is located in biomass, and only 32% in soils (Pan et al. 2011). As a consequence, carbon densities (i.e. quantity of carbon stored per ha) in boreal forests are as high as in tropical forests (239.2 Mg ha^{-1} vs. 241.6 Mg ha^{-1}). Temperate forests, in contrast, show lower carbon densities (mean: 154.7 Mg ha^{-1}), although peak values up to 260 Mg ha^{-1} are possible (Pan et al. 2011); data for the year 2009). When total areas of forest biomes are taken into account, tropical forests constitute the most important carbon sink (471.0 Pg ha^{-1}), followed by boreal and temperate forests 271.5 and 118.6 Pg ha^{-1}, respectively (Pan et al. 2011). In summary, forest ecosystems contain about 50% of the world's terrestrial global carbon stocks, and their biomass constitutes about 80% of the terrestrial biomass. This underpins the pivotal role of forests in the global carbon cycle, and hence the potential of sustainable forest management in mitigating global climate change (Erb et al. 2018).

3 Biodiversity Patterns and Drivers of Biodiversity Losses

3.1 Biodiversity Patterns: A Comparison Across Forest Biomes

Tropical forest ecosystems represent the world's most preeminent biodiversity hotspots (Giam 2017; Myers et al. 2000). It is estimated that tropical rain forests support about two-thirds of the global biodiversity, despite covering less than 15% of the world's land surface (Gardner et al. 2009; Giam 2017). It has been hypothesized that this extraordinary species richness is attributable to several processes and mechanisms, for example the long persistence of evolutionary processes, mid-domain effects (i.e. effects related to geometrical/geographical characteristics), climatic conditions prevailing in the tropics, and the structural (i.e. habitat/niche) diversity typical of tropical forests (which in turn supports many stenotopic species; Sherratt and Wilkinson 2009; Nice et al. 2019). The tremendous diversity of tropical forests has been observed across different taxonomic groups (Myers et al. 2000), such as vascular plants, arthropods, reptiles, amphibians, fishes or birds. Forests of the upper Amazonian, for example, are considered the most tree species-rich in the world: In two study plots established in tropical forests near Iquitos (Peru), Gentry (1988) recorded about 300 tree species per hectare. Besides the Amazonian basin, tropical forests in China and Indonesia are also known to constitute hotspots for (woody) vascular plants (Barthlott et al. 2007). Related to plant diversity, tropical forests also host a huge proportion of the world's terrestrial arthropod (and thus insect) diversity, the most diverse taxonomic group among all eukaryotic organisms. Although estimates are still fraught with uncertainty, recent models predict tropical arthropod diversity to range between 2.5 and 3.7 million species (medians), of which approximately 70% remain scientifically undescribed (Hamilton et al. 2010). Among arthropods, beetles in turn represent the most important taxonomic group (Hamilton et al. 2010; Stork et al. 2015). Despite uncertainties in arthropod species estimates, several field studies provided concrete numbers on area-related patterns in species richness. In tropical rain forests in Panama (San Lorenzo), for example, Basset et al. (2012) collected 6144 arthropod species from 0.48 ha. The authors extrapolated this finding to larger areas, and concluded that the whole 6000-ha forest reserve sustains about 25,000 arthropod species.

As suggested by maps illustrating global biodiversity patterns, there is a strong latitudinal diversity gradient (Barthlott et al. 2007), with a continuous decline in species richness across different taxonomical groups from the tropics to the polar zone. Many angiosperm families, for example, are restricted to the tropics (Sherratt and Wilkinson 2009), a pattern that also applies to other taxonomic groups such as arthropods, amphibians, or fishes. As a consequence, forest area-related species richness decreases from tropical to subtropical, to temperate and boreal forest ecosystems. Observable relationships between the latitudinal decline in plant diversity and (e.g.) insect diversity suggest that the latitudinal gradient in insect species richness could be a direct function of plant diversity, which increases sevenfold from temperate to tropical forests (Novotny et al. 2006).

3.2 Drivers of Biodiversity Loss

There are six major drivers of biodiversity loss acting across forest types: deforestation, overexploitation, failure of protection, climate change, pollution, and invasive species (also cf. MEA 2005 and Mazor et al. 2018). According to IUCN analyses (2019), the importance of globally acting drivers of biodiversity loss decreases in the order: 'Biological resource use' (particularly wood harvest and logging), 'Agriculture', 'Natural system modifications', 'Residential and commercial development' (particularly development of urban areas), 'Pollution', and 'Climate change' (Maxwell et al. 2016; IUCN 2019).

Significant losses of forest area have been documented for the tropics in particular. In the years 1990–2005, the net loss of natural tropical forest area was estimated to 135 million hectares (with the highest total losses (i.e. across biomes) found in South America (62 million ha) and Africa (61 million ha); Table 1; FAO 2015, Keenan et al. 2015). In contrast, a net increase of forest area was observed in temperate forests during this period (41 million ha), mainly attributable to the establishment of plantations or reforestation projects or the natural expansion of forest area. The most important driver of global forest diversity loss is deforestation, mostly attributable to the conversion of forests to agricultural area by slash-and-burn or wood harvest. Declining forest area threatens biodiversity at all levels. Considering trees, more than 5000 species from 180 countries are currently threatened with extinction (IUCN 2019). Given that 15 of the 25 global ‘biodiversity hotspots’ identified by Myers et al. (2000) represent tropical forests, deforestation in the tropics has by far the most dramatic consequences for global biodiversity. All tropical ‘hotspots’ once covered about 12.5% of the Earth’s land surface, but their remaining area now amounts to 1.4%, indicating a 88% loss of the former area (MEA 2005). If current rates of tropical rainforest clear-cuts remain unchanged, Pimm and Raven (2000) predict that species extinction rates achieve a maximum by 2060, with decadal losses of nearly 5% of the total species richness of tropical forests.

Shifts in forest cover (across biomes) in turn will feedback on important functions of forest ecosystems. For example, analyses of (Alkama and Cescatti 2016) showed that forest losses amplify the diurnal temperature variation and increase the mean and maximum air temperature, with the largest signal in arid zones, followed by temperate, tropical, and boreal zones. The authors further demonstrated that variations of forest cover (related to the decade 2003–2012) generated a mean biophysical warming on land corresponding to about 18% of the global biogeochemical signal due to CO_2 emission from land-use change.

The term “overexploitation” summarizes all forms of unsustainable use of forest area (e.g. wood harvest exceeding natural regrowth), including failure in forest management measures due to missing or inappropriate management plans. Overexploitation or management failure result in habitat and finally diversity losses (Stork et al. 1997), but the underlying mechanisms are manifold. Despite the complexity of processes, it is clear that overexploitation is a result of many direct or indirect drivers, with specific combinations of drivers varying between countries or localities (MEA 2005). Intensively managed forests, for example, suffer from a lack of sites that remain undisturbed in the long term and therefore often are missing an ‘ecological continuity’ being important for the course of undisturbed ecological processes and the establishment of many stenotopic forest species (Maes et al. 2019; also cf. Sect. 4.2). ‘Legacy effects’ of forest management in turn may increase a forest’s sensitivity to climate extremes (Mausolf et al. 2018a). Forest management shortens the life cycle of trees (in most cases more than 50%), reduces the formation of dead wood (i.e. missing old trees, missing dead wood), and impairs the textural diversity by preventing the establishment of developmental phases typical of forest ecosystems (e.g. missing terminal or decay phase, reduced structural diversity in space and time). Since many forest species (particularly fungi or xylobiontic species) depend on the presence of old or dead trees, they often failure to develop stable populations in managed forests (Fichtner et al. 2015; Heilmann and Christensen 2004; Moning and Muller 2009). Moreover, the establishment of monocultures or stands with non-native tree species may negatively affect both forest diversity and productivity, particularly at sites with high natural tree diversity (Huang et al. 2018; cf. Sect. 5.3).

During the last 30 years, forest ecosystems have been increasingly subject to climate change (MEA 2005; IPCC 2013). Because climate change alters (and will continue to alter) the spatial and temporal patterns of temperature and precipitation—the two most fundamental factors driving distribution and productivity patterns of vegetation—climate change will cause geographical shifts in the ranges of species, plant communities and vegetation zones (MEA 2005). Aitken et al. (2008) developed species distribution models, according to which a global redistribution of trees might be expected in upcoming decades, yet migratory responses necessary to spatially track climate shifts far exceed the species' maximum post-glacial migration rates. In the case of limited migration rates, (long-distance) gene flow can promote adaptive evolution under novel environmental conditions by increasing genetic variation for fitness (Kremer et al. 2012). Aitken et al. (2008) hypothesize that gene flow with preadapted alleles from warmer climates may promote adaptation and migration at the leading edge, while populations at the rear more likely will face extinction. However, despite possible range shifts and the adaptive potential of tree species, climate change affects forest ecosystems not only through direct physiological effects such as modifying photosynthesis and growing season lengths, but also through indirect effects via shifts in community composition related to species extinctions and colonizations (i.e. climate change induced shifts in competitive interactions between tree species; Garcia-Valdes et al. 2018). In a tree species hotspot in the tropical Andes, Garavito et al. (2015) analyzed the relative impact of climate change on the extinction risk of 129 tree species endemic to this region. The authors demonstrated that climate change significantly increases the extinction risk of 18–20% of the tree species evaluated, depending on the climate change scenario considered. Strong shifts in tree species composition are also expected for regions with arid climatic conditions, for example in the Mediterranean area. Analyses of Benito Garzon et al. (2008) conducted for the Iberian Peninsula showed a notable reduction in the potential distribution of several tree species under all the IPCC scenarios (e.g. *Pinus sylvestris*, *P. uncinata* and *Abies alba*); temperate tree species such as *Fagus sylvatica* and *Quercus petraea* were also predicted to suffer a reduction in their range, whereas Mediterranean species appeared to be generally more capable of migration, and are therefore likely to be less affected (Benito Garzon et al. 2008). Climate change may not only cause range shifts of a focal tree species, but also could foster a large-scale fragmentation of species distributions with consequences for meta-population dynamics and gene flow. For boreal forests in North America, Murray et al. (2017) demonstrated that climate change directly alters environmental niche suitability for boreal-obligate species of trees, birds and mammals, with most species ranges becoming smaller and shifting northward over time. Importantly, species distributions became increasingly fragmented, as characterized by smaller mean areas and greater isolation of environmentally-suitable landscape patches (Murray et al. 2017).

Besides climate change, pollution—namely the deposition of reactive forms of nitrogen (N) from the atmosphere—constitutes a further important driver of biodiversity loss across forest biomes (Galloway et al. 2004; Gruber and Galloway 2008; IUCN 2019). Airborne N deposition has tripled since the beginning of industrialization (Galloway et al. 2004), resulting in unprecedented impacts on the N status of many forest ecosystems (De Schrijver et al. 2011). Since N is often the most limiting nutrient for plant growth, high N loads may affect ecosystem functions such as biomass production and the complex interplays within and between tree species, but also their susceptibility to abiotic and biotic stressors such as drought, frost events and herbivory (Bobbink et al. 2010; Hess et al. 2018). This pertains to strongly N-limited sites with conservative N cycles in particular (e.g. forests at acidic or podzolic sites), because many species typical of these sites are physiologically adapted to low N availability, for example due to high N use efficiency or mycorrhizal associations (Aerts 1999; Phoenix et al. 2012). Besides the direct effects of N deposition on forest species competition and performance, atmospheric N deposition has been shown to interact with drivers of climate change, e.g. increasing temperature or drought events. Taking European beech forest ecosystems as example, Hess et al. (2018) demonstrated that high rates of airborne N loads significantly increases the trees' sensitivity to increasing annual mean temperatures (antagonistic effects on tree-ring width), possibly due to N deposition-induced fine root dieback, decreasing mycorrhizal colonization or shifts in biomass allocation patterns (i.e. increasing aboveground, but decreasing belowground biomass allocation; Agren and Franklin 2003). Effects of N deposition may also interfere with increasing CO_2 concentrations in the atmosphere. Many experiments with leaves, shoots, and tree seedlings indicated a significant increase of productivity due to "CO_2 fertilization", but these effects on forests may be saturated within a short time span (Scholes et al. 1999). This conclusion is supported by experimental data, according to which "fertilization" effects due to increasing CO_2 levels are low (Bader et al. 2013; Korner 2003).

In some areas, losses in biodiversity are also driven by invasive tree or shrub species. Many woody species have spread from planting sites, and some are now among the most widespread and damaging of invasive organisms (Richardson and Rejmanek 2011). Across the globe, the authors identified 434 tree species and 317 shrub species as being "invasive outside their natural range", and both further spreads and impacts of these species on biodiversity and ecosystem functioning is strongly accelerating (Rejmanek and Richardson 2013). Invasive woody species constitute a particular threat in North America (212 species), the Pacific Islands (208), Australia (203), Southern Africa (178), and Europe (134), indicating that these neobiota affect forest ecosystems across biomes. In a case study conducted in riparian forests invaded by *Eucalyptus* species, Tererai et al. (2013) found that forest species richness, diversity and structural attributes (e.g. height, relative cover and mean basal area) of native species decreased consistently along an invasion gradient. These findings indicate the importance of native tree species to be used in the context of afforestation projects (cf. Chap. 5.3).

4 A Functional-Based Perspective on Forest Ecosystems

4.1 Biodiversity and Forest Ecosystem Functioning

During the last two decades experimental and observational studies provided ample evidence for positive links between biodiversity and ecosystem functions, such as productivity (Hector et al. 1999; Gamfeldt et al. 2013; Grace et al. 2016; van der Plas 2019). Across a wide range of biomes, tree species richness has been demonstrated to enhance forest productivity (Paquette and Messier 2011; Zhang et al. 2012; Liang et al. 2016; Huang et al. 2018) by resource partitioning (Jucker et al. 2015; Schmid and Niklaus 2017; Williams et al. 2017), facilitation (Fichtner et al. 2017), natural enemy (e.g. pathogens or herbivores) partitioning (Jactel and Brockerhoff 2007; Grossman et al. 2019) or selection effects (the increased likelihood of including dominant and well-performing species in diverse communities; Tobner et al. 2016). Detailed information on processes underlying relationships between biodiversity and ecosystem functioning is provided by Forrester and Bauhus (2016), Wright et al. (2017) or Barry et al. (2019).

The positive effects of biodiversity on forest ecosystem functioning often arise due to local species interactions. Mixed-species plant communities are a network of locally interacting individuals. Consequently, the response of tree communities to species mixing should be—at least to a certain extend—the result of aggregated small-scale variations in neighbourhood interactions (Stoll and Weiner 2000). Results from a large-scale biodiversity-ecosystem functioning experiment in the subtropics support this theory by demonstrating that neighbourhood interactions explain over half of the variation in forest community productivity along a tree diversity gradient (Fichtner et al. 2018). This implies that diversity-mediated interactions among local neighbours are highly relevant for enhancing productivity in mixed-species forests—particularly in highly diverse forest communities of the subtropics and tropics. Maintaining high tree diversity not only supports ecosystem functioning, but also socio-economic issues. For example, both experimental (Huang et al. 2018) and observational (Liang et al. 2016) studies predicted that a 10% decline of tree species richness might result in a reduction by 2–3% of forest productivity on average at the global scale. Although biodiversity has an intrinsic value, Liang et al. (2016) estimated a monetary value of tree species richness in maintaining commercial forest productivity of $166 billion to $490 billion per year.

Forest biodiversity may also play a critical role in mitigating adverse climate change impacts on forest ecosystem functioning (Hisano et al. 2018; Ammer 2019; Anderegg et al. 2018). Globally, forests sequester and store immense amounts of carbon (Pan et al. 2011). This role, however, can be altered by biodiversity loss, as higher tree productivity of species-rich forests translates in higher amounts of carbon stored above- and belowground in the ecosystem (Chen et al. 2018; Liu et al. 2018). Moreover, tree species richness increases the stability of forest productivity (Jucker et al. 2014; Morin et al. 2014; Schnabel et al. 2019), which in turn favours future carbon sequestration. For example, aboveground biomass production was shown to be higher and aboveground biomass loss due to tree mortality was lower in species-rich than in species-poor boreal forest over the last five decades (Hisano et al. 2019).

In the context of ongoing global insect decline (Hallmann et al. 2017) recent results from two of the world's largest biodiversity-ecosystem functioning experiments in different ecosystems (grasslands and forests) provided evidence that maintaining high levels of plant diversity and the associated structural diversity increases the abundance and richness of insects (Schuldt et al. 2019). This emphasizes that ongoing global overexploitation of agricultural and forest ecosystems can lead to drastic decline or even loss of basic ecosystem services, such as pollination or the regulation of pests. Thus, extensive management approaches and restoration programmes can significantly contribute to multitrophic biodiversity conservation and the future provisioning of ecosystem services.

The importance of biodiversity in maintaining multiple ecosystem functions and services on which humans depend increases as more functions are considered (ecosystem multifunctionality; Gamfeldt et al. 2008). Across biomes and spatial scales, there is now increasing evidence that biodiversity enhances a multitude of functions that forest ecosystems simultaneously provide for human well-being (Gamfeldt et al. 2013; van der Plas et al. 2016; Ratcliffe et al. 2017; Schuldt et al. 2018; van der Plas et al. 2018). Promoting high levels of multiple ecosystem services therefore requires conservation and restoration measures within and among ecological communities, as well as measures for less prominent taxa, such as soil microorganisms. Although often overlooked, belowground biodiversity is an important component of terrestrial biodiversity accounting for roughly 25% of global biodiversity (George et al. 2019). Soil biota play a vital functional role in the provisioning of ecosystem services, such as nutrient cycling or carbon storage (Bardgett and van der Putten 2014; Adhikari and Hartemink 2016). Above- and belowground forest biodiversity is not always closely related and its ratio depends on the biome. For example, the tropical and subtropical moist broadleaf forests biome is a biodiversity hotspot both above- and belowground. Contrarily, the temperate broadleaf and mixed forests biome contain more species aboveground, while the opposite holds for boreal and tundra biomes (Cameron et al. 2019). Accounting for soil biodiversity—particularly in boreal, subtropical and tropical forest ecosystems—appears therefore crucial to ensure the reliable provision of ecosystem services. These examples illustrate the functional importance of forest biodiversity and emphasize the vital importance of safeguarding forest biodiversity across trophic levels for future human well-being.

4.2 Linking Biodiversity and Ecological Continuity of Forest Ecosystems

Disruption of ecological continuity due to land-use change or land-use intensification can trigger biodiversity loss, and thereby changes in ecosystem functioning. Here, we use the term 'ecological continuity' in an ecosystem-based sense, meaning the continuity in biotic and abiotic forest ecosystem processes that develop without land-use change, forest management or significant silvicultural interventions. A long ecological continuity is therefore commonly associated with a high integrity in habitat structures, species composition, species interactions, soil conditions and biogeochemical cycles typical for a given forest type. Importantly, ecological continuity refers to three different aspects that determine how forests mature: forest continuity, stand maturity and continuity in natural stand dynamics. Forest continuity refers to the temporal extend of how long a given site is wooded (i.e. the maintenance of the forest cover over time including soil development). For example, forest sites that have been continuously wooded for at least more than two centuries have been described as 'ancient forests' (Peterken 1977; Rackham 1980) in contrast to 'recent forests' that are afforested during the last two centuries on former agricultural land. The reference date for 'ancientness', however, is still on debate (see Bergès and Dupouey 2020). Stand maturity is associated with tree and stand aging, and thereby with processes regulating the availability, continuity and diversity of habitat structures (Janssen et al. 2019). The continuity in natural stand dynamics refers to the duration of stand development without anthropogenic disturbances, which depends on the length of forest management cessation or the frequency and intensity of silvicultural interventions (e.g. thinning or commercial harvesting). Note that a long-term forest continuity does not necessarily imply a high stand maturity or long-term natural stand dynamics, although each aspect determines the conservation value (Watson et al. 2018; Janssen et al. 2019; Bergès and Dupouey 2020) and ecological integrity of a forest.

There is mounting evidence that ancient forests harbour higher abundance and richness of forest species on average than recent forests due to dispersal and recruitment limitations (Brunet and von Oheimb 1998; Flinn and Vellend 2005; Fritz et al. 2008a; Seibold et al. 2015; Flensted et al. 2016). Similarly, a large proportion of forest species—across taxa—depends on structures associated with late forest development phases and 'old-growth' forests (i.e. primeval or long-term unmanaged forests). For example, this includes high growing stocks and a high quantity and quality of dead wood, a wide range of tree sizes, a high spatial heterogeneity, a high variety of host species in various microclimates and a high abundance of senescent and large-diameter trees (Christensen et al. 2005; Bauhus et al. 2009; Brunet et al. 2010; Krah et al. 2018). Overall, old and large-diameter trees exhibit higher diversity of microhabitats than young trees (Fig. 2) and are important for forest structural heterogeneity and functional complexity (Lutz et al. 2013). At the forest stand scale, forest continuity and stand maturity are key factors regulating the availability of substrates required for many species of conservation concern (Fritz et al. 2008a; Janssen et al. 2017)—specifically, the abundance and continuity of habitat structures as well as the variability in microclimates associated with late forest development phases (terminal and decay phase). Consequently, biome-specific biodiversity increases in a wide range of taxa with habitat continuity (Ohlson et al. 1997; Nordén et al. 2014), tree/stand age (Heilmann and Christensen 2004; Fritz et al. 2008b; Moning and Muller 2009; Moning et al. 2009) and length of forest management abandonment (Paillet et al. 2010; Alroy 2017; Kaufmann et al. 2018). Ancient forests are therefore priority sites for species conservation (Flensted et al. 2016; McMullin and Wiersma 2019). Consequently, land-use changes or intensive forest management of ancient forest sites would contradict biodiversity conservation. Moreover, forest management should focus on promoting the continuity of habitat structures, species interactions and species composition, which in turn would benefit synergies among multiple forest ecosystem services (Felipe-Lucia

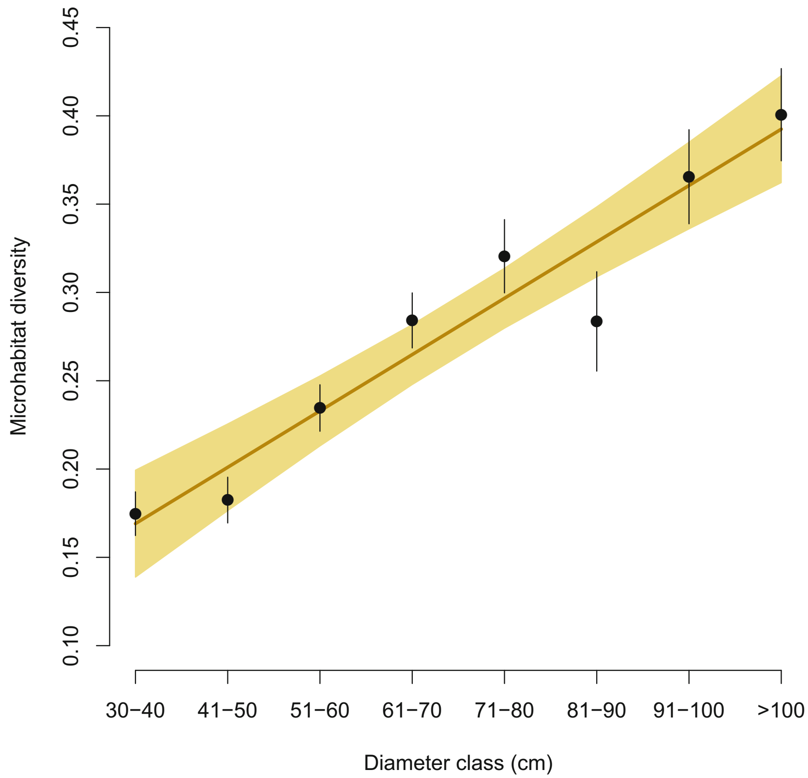

Fig. 2 Microhabitat diversity increases continuously with tree size. Relationship between microhabitat diversity (Simpson's diversity index) and tree size (diameter at 1.30 m). Points represent means (± standard errors) of a given diameter class based on 2633 trees (deciduous: 2107, coniferous: 526) growing in temperate forests. The solid line is a linear model fit (r^2: 0.93, $P < 0.001$), with shaded area representing the 95% confidence interval of the prediction. Data were obtained from Fichtner and Schmid (2015)

et al. 2018) and the diversity of multiple trophic groups (Penone et al. 2019). Forest management should also focus on promoting multiple ecosystem functions rather than a small subset of functions at a very high level (e.g. maximum timber production) to ensure positive forest biodiversity-multifunctionality relationships (van der Plas et al. 2016). This would offer a high potential for accounting a multitude of stakeholder requirements, because trade-offs among different measures of forest multifunctionality tend to be rare, as shown for European forests (van der Plas et al. 2018; Baeten et al. 2019).

Next to the importance of ecological continuity for biodiversity, various forest ecosystem functions and services are positively related to ecological continuity. For example, large-diameter trees constitute about half of the mature forest biomass worldwide (Lutz et al. 2018). Large-sized trees are also assumed to be those which accumulate carbon in the trunk at even faster rates as they mature, suggesting that not only the amount of carbon, but also carbon sequestration is highest in those trees (Stephenson et al. 2014; Fichtner et al. 2015). Moreover, stand age and tree species richness enhance the stability of carbon sequestration in forest ecosystems (Musavi et al. 2017), and old forests continue to sequester carbon for many centuries (Luyssaert et al. 2008). This is particularly relevant for the current debate on natural carbon dioxide removal measures (Griscom et al. 2017), as these findings suggest that restoring natural forests by allowing for senescence and promoting biome-specific tree diversity would offer a high potential for meeting global climate and biodiversity agreements (Körner 2017; Lewis et al. 2019). In addition, maintaining old and large-diameter trees is functionally important for belowground networking. Trees can transfer carbon, water, nutrients and biochemical signals belowground via mycorrhizal networks (Simard et al. 1997; Gorzelak et al. 2015) and can become more connected as they grow larger in size (Beiler et al. 2010). Such common mycorrhizal mycelium links the roots of trees by which mature trees transfer substantial amounts of carbon (280 kg carbon per hectare and year, equivalent to 4% of the forest's net primary productivity) from one tree to another– even between species (Klein et al. 2016). Belowground transfers have therefore important implications for local tree-tree interactions, facilitation of conspecific regeneration, maintaining biodiversity and may become increasingly important in a changing climate (Beiler et al. 2010; Simard et al. 2012). The development of mycorrhizal networks might also one reason why trees growing in unmanaged forests were found to be less sensitive to drought-induced growth decline than trees growing in managed forests (Mausolf et al. 2018a). This implies that intensive logging and logging-associated soil compaction might disrupt mycorrhizal networks and induces long-lasting impacts on the soil microbiome (Hartmann et al. 2014), which in turn would lead to a decline in ecosystem functioning and eventually to a loss of ecosystem stability. Moreover, ecological continuity is closely linked to legacies of former land use, and such land-use legacies have been suggested to mediate the response of forest ecosystems to global environmental change (Perring et al. 2016). For example, soil legacies have been shown to alter carbon and nutrient cycling (Compton and Boone 2000; von Oheimb et al. 2008; Leuschner et al. 2014) due to changes in the soil microbiome (Fraterrigo et al. 2006; De la Peña et al. 2016)—even after more than one century (Fichtner et al. 2014). These altered edaphic conditions in turn can impose long-lasting impacts on a trees' fine root system, which is crucial for its nutrient and water uptake. In this context, it has been demonstrated that forest continuity increases the resistance of adult beech trees (*Fagus sylvatica*) to drought by modulating fine root morphology and increasing standing fine root biomass (Mausolf et al. 2018b).

These examples highlight that forests associated with a long ecological continuity not only host a high diversity of biome-specific forest species, but may be even more resilient to multiple environmental changes. Sustaining and promoting ecological continuity would therefore benefit both biodiversity conservation and the mitigation of adverse climate change impacts, which in turn would resolve conflicting assumptions about biodiversity and climate goals.

5 Solutions for Safeguarding Forest Biodiversity and Forest Ecosystem Functioning

Loss of ecosystem functions and associated services in the context of global change are amongst the most important ecological threats for humanity in the twenty-first century. Here, we emphasize the vital importance of safeguarding biodiversity and sustaining ecological continuity to tackle these challenges. This would lead to co-benefits from management, conservation and restoration measures under multiple international environmental agreements, such as biodiversity conservation and climate change mitigation.

5.1 Wilderness Areas and Forest Protection

The most important step to protect forest diversity (at all diversity levels, i.e. α-, β- and γ-diversity) is to increase the total protected forest area (i.e. wilderness areas with no or almost no human interference) across all forest biomes.

Forest wilderness areas provide an optimal protection of forest biodiversity, because these areas allow for an optimal development of ecological processes (cf. Sect. 4.2), which in turn support a maximum of diversity typical of the respective ecosystems. The success in biodiversity conservation in turn provides an important indicator for assessing the sustainability of forest protection and management (Stork et al. 1997).

The highest percentage of protected areas is found on the American continent (about 20%) and the lowest in Europe (about 5%; MEA 2005). As a consequence, European countries in particular need to enlarge their wilderness areas in forest ecosystems typical of Europe, for example in beech forests (with dominant *Fagus sylvatica*), which are restricted to the temperate zone of Europe).

The increase in forest wilderness areas needs to be shaped by participative processes including local communities and stakeholders to improve acceptance and to avoid illegal activities such as logging, wildlife poaching or agricultural encroachment (Barber et al. 2004).

5.2 Ecosystem-Based Forest Management

Forest management often has strong impacts on biodiversity and ecosystem functioning, as key attributes for forest species conservation and ecological processes critically depend on management intensity (Erb et al. 2018; Watson et al. 2018). Consequently, allowing a maximum temporal extent of anthropogenic undisturbed ecological processes and species interactions by minimizing silvicultural interventions is one of the most important measures for safeguarding biome-specific biodiversity in managed forests and their reliable provisioning of ecosystem services.

Natural forest development requires space and time. To preserve biodiversity and sustain ecological continuity in managed forests therefore requires management strategies that (1) avoid deforestation and land-use changes, (2) approach key attributes of 'natural forest communities' (e.g. biome-specific tree species composition and diversity), (3) allow for senescence and natural disturbances (e.g. fires, windstorms, insect outbreaks) as well as (4) prioritize the minimization of silvicultural interventions (Fähser 2012), and thus the optimization of forest ecosystem functioning over the maximization of forestry use (e.g. maximum timber production due to short-term rotation periods, intensive thinning or clearcutting). This ecosystem-based management approach aims at sustaining ecological integrity (ecological processes and biodiversity) in managed forests by taking nature as role model. Specifically, this includes promoting biome-specific tree species composition and diversity, maintaining old and large-diameter trees, maintaining trees with microhabitats and rare tree species, using single-tree or group selection harvesting, avoiding deforestation and planting of non-native tree species, avoiding harvester and tillage, avoiding application of fertilizer, pesticides and drainage. In this context it should be noted that the reliable provisioning of wood supply may require additional agroforestry to prioritize ecosystem functioning, biodiversity conservation and recreation over wood production in natural forests.

5.3 Forest Restoration

In the context of biodiversity conservation and climate change mitigation, regeneration of natural forests should be should be prioritized over afforestation measures, such as establishing plantations that fail long-term ecological and social benefits (Lewis et al. 2019). Similarly, biodiversity typical of cultural-based ecosystems (e.g. grasslands or heathlands) should not be sacrificed for large-scale tree planting programmes (Seddon et al. 2019; Temperton et al. 2019).

Recent meta-analyses have demonstrated that high levels of species diversity are needed to support multiple ecosystem functions und the services provided by forest ecosystems (Isbell et al. 2011). This also applies to the potential of forest ecosystems to sequester carbon and thus to contribute to climate change mitigation. In a large-scale subtropical forest experiment, for example, Huang et al. (2018) have demonstrated that 16-species mixtures had accumulated over twice the amount of aboveground carbon found in average monocultures after 8 years. Given that tree species richness at the local neighbourhood scale enhances forest productivity (Fichtner et al. 2018) and increases resistance of forests to drought (Fichtner et al. 2020), restoration and reforestation strategies should therefore prioritize planting mixtures over monocultures by mixing tree species at the smallest spatial scale (i.e. the local neighbourhood level) instead of mixing monospecific patches or forest stands at the stand or landscape scale—particularly in highly diverse forest communities such as subtropical or tropical ecosystems. Here, it is important to note that the preservation of natural old-growth forests has a larger (mitigation) effect on the carbon cycle than promotion of regrowth (i.e. establishment of young forest plantations; Schulze et al. 2000; Körner 2017).

Forests should be restored by using biome-specific tree species instead of planting non-native trees and ideally, trees grew from seeds instead of using nursery plants associated with root pruning. Next to assisted regeneration and reforestation, natural regeneration of tropical secondary forests is suggested an effective forest restoration strategy to enhance biodiversity and carbon sequestration (Chazdon et al. 2016). Specifically, in the tropics a large proportion of restoration hotspots coincidence with conservation hotspots (Brancalion et al. 2019).

The more intensive (forest) ecosystems are managed, the lower their potential to store carbon in the long term and the lower biome-specific biodiversity. Erb et al. (2018) have demonstrated that in the (hypothetical) absence of land use, potential vegetation would store twice the amount of carbon as terrestrial vegetation currently does (415 vs. 916 petagrams of carbon; calculated for current climate conditions). Therefore, forest management contributes two thirds to total management-induced differences in biomass stocks (i.e. managed vs. unmanaged forests; Erb et al. 2018). This indicates that altering forest management schemes towards a low-impact approach (as described above) or abandonment of silvicultural measures would offer a great opportunity for both biodiversity conservation and climate change mitigation, although the role of forests in mitigating climate change impacts is controversially discussed (see Popkin 2019).

One of the main challenges in future would be to find social-ecological solutions to stop overexploitation and poaching (particularly in tropical and subtropical forests), while addressing the needs of many people depending on forests for their livelihood.

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The Future of Agricultural Land

Joop H. J. Schaminée and Nils M. van Rooijen

Abstract From the moment people started to settle, agriculture became a common and rapidly increasing form of land use, having a huge impact on nature and landscape on all continents. An impact much greater than even urbanisation and increasing infrastructure. Nowadays, agricultural activities directly influence more than 38% of the world's land surface. Two major practices must be distinguished: on the one hand the production of crops on arable land, and on the other hand livestock farming. The focus in this chapter is on the production of crops on arable land. An exception is made for two examples on the landscape level, which will be discussed here. These refer to traditional agricultural land use systems, one from the low mountain ranges of Central France and one taken from the Northwest European lowlands.

After a general introduction on the worldwide distribution of agricultural land and the focus on strong mechanisation in modern agriculture, a wide spectre of issues will be addressed. This includes issues like: how are world processes affected by agricultural land use in history and present times, what is the origin of species that are accommodated in agricultural ecosystems, and what is the relationship between agriculture and nature, regarding different levels of farming.

Keywords Agriculture · Arable crops · Living archives · Traditional land use · Co-evolution · Genetic manipulation · Organic farming

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1 Introduction

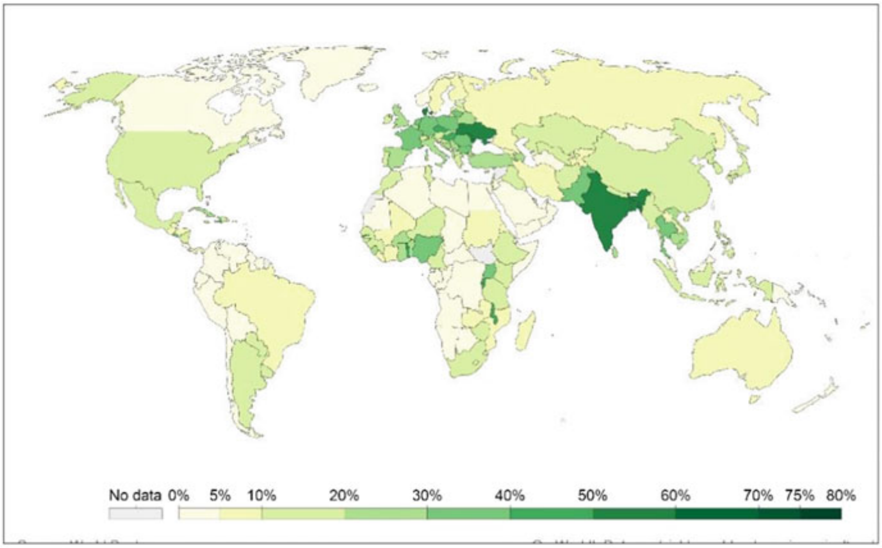
More than 13,000 years ago, mankind made a world-changing decision by settling down. The nomadic way of life by hunting and gathering, in which people were ruled by nature, transformed into a domestic lifestyle, in which people shaped and exploited their natural environment for the production of food: agriculture was born (Larson et al. 2014). Worldwide, at least eight centres of origin can be distinguished. In the Levant, grains, peas and flax were cultivated since 11,500 years ago. In China, rice was cultivated more or less around the same time, whereas a couple of thousand years later sugarcane became a crop in New Guinea. At the other side of the Pacific, potatoes, coca, cotton and maize were grown in Middle and Latin America, more precisely in Mexico, Peru, Chile and Brazil. Apart from these crops, a decisive development was also the domestication of animals. Wild aurochs were transformed into cattle about 10,500 years ago in Turkey and Pakistan, while over a large area in Europe and Asia, pigs were bred from wild boars. Sheep were domesticated in Mesopotamia, already two thousand years earlier (https://en.wikipedia.org/wiki/History_of_agriculture). Both the production of crops on arable land and the livestock farming on grazing grounds changed our landscapes worldwide.

From this early start, agriculture has spread enormously and become dominant in large parts of the world. Currently, agriculture covers more than 38% of the world's land surface. Permanent pastures account for more than two-third of this area; most of the rest is used for cultivating crops (FAOSTAT 2019; Ritchie and Roser 2019). Agricultural land is widespread worldwide, found on all continents, with the emphasis on temperate and tropical climate zones; in the circumboreal regions, the conditions are too restrictive as in the larger deserts.

The distribution of temporal arable land and land under permanent use for crops or pastures (with herbaceous forage crops, either cultivated or growing wild) is showing some clear contrasts. For most countries, the majority of agricultural land is used for livestock rearing in the form of pastureland. In Europe and South-Asia, however, the amount of land used for livestock is much lower than for arable farming, less than 20% (Fig. 1).

To sketch future scenarios with perspectives for sustainable agriculture and biodiversity conservation, it is necessary to have insight in driving forces that have constituted our present agricultural landscape. We will explore and illustrate the complexity of the topic by addressing various aspects of this agricultural tapestry.

In modern, heavily mechanized agriculture, specialisation is a dominant factor. Nowadays, two of the main agricultural activities (crop cultivation and grazing) are generally separated on the level of individual farmers and farming systems, and at the same time scaled up to a degree never seen before. In the US, as an example, the average farm size (in 2017) is 444 acres, and still increasing. Each year since 2012, the average size has been expanded approximately two acres per farm, whereas the number of farms is gradually decreasing (www.usfarmdata.com). In the US, the centre of agricultural activity has to be looked for in the Great Plains, a vast and generally flat area, west of the Great Lakes and east of the Rocky Mountains. The



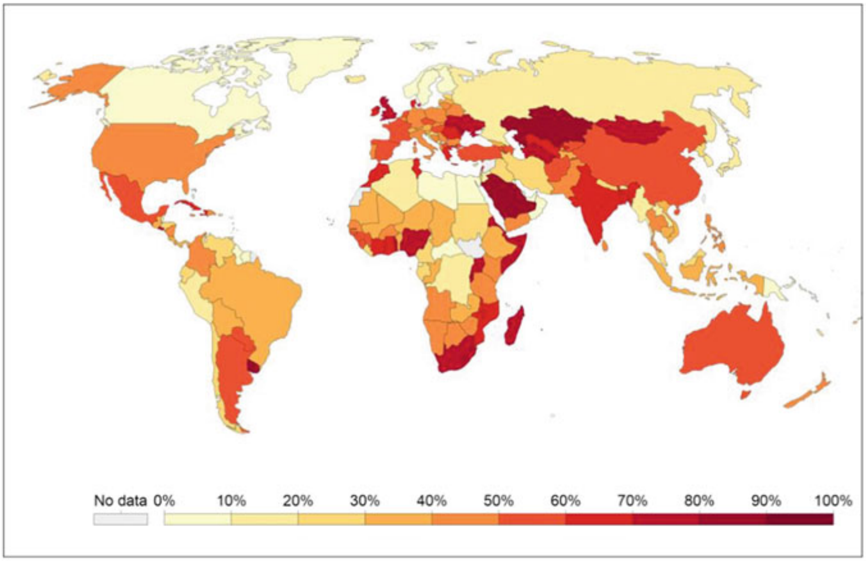


Fig. 1 Share of land area worldwide used for agriculture, measured as a percentage of total land area in 2015 (**a**). Agricultural refers to the share of land that is arable, under permanent crop or under permanent pastures. (**b**) Depicts the share of land area under arable use. Arable land in this context includes land defined by the FAO as land under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow (Ritchie and Roser 2019)

Fig. 2 Wheat harvest in Idaho, US (ars.usda.gov, Image Number k1441-5)

relatively wet eastern half of these plains are a major corn and soybean producing region, known as the Corn Belt, whereas the drier western parts, known as the Wheat Belt, produce high rates of wheat. Currently, the yearly production of corn (maize) in the United States is more than 400 million tons, which counts for about one-third the worldwide production, more than the production of any other grain in the world (International Grains Council 2019). Approximately 40% of the crop is used for corn ethanol (*The New York Times*, 11-02-2011). The percentage of genetically modified corn (*Zea mays*) planted in the United States is increasing exponentially, from less than 10% in 1999 to more than 85% in 2009 (www.gmo-compass.org).

The annual US wheat production is about 80 million tons, of a worldwide total of more than 1000 tons. In the USA, currently most cropland is on farms with at least 1100 acres, and many farms are five to ten times that size (MacDonald et al. 2013; Fig. 2).

These figures are in strong contrast when looking at the worldwide distribution of farms and farm sizes. Based on agricultural census data from 167 countries, Lowder et al. (2016) calculated that there are more than 570 million farms worldwide. Of these, 72% of the farms are smaller than 1 ha, and only 6% of the world's farms are larger than 5 ha. The situation in the USA more or less reflects the situation in the European Union. Here, 50% of the farms are smaller than 2 ha, operating on less than 2% of the agricultural land.

Before discussing the complexity of the topic by addressing various aspects of agricultural land use, we will pay attention to some of the traditional agricultural systems that have been of great influences on the landscape development, in a time before specialisation became a dominant factor. We will describe two of such systems in Europe, one from the mountains of Central France and one from the lowlands in the Northwest of Europe (Germany and The Netherlands).

2 Traditional Land Use at the Hautes Chaumes in Low Mountain Ranges of Central France

Heathlands and grasslands still form a characteristic component of the subalpine landscape in European low mountain ranges, although the switch from traditional management practices put these systems nowadays under great pressure. For centuries, the highest parts of these mountain ranges (called *hautes chaumes* in France) were used for cattle grazing and the pastured land was held in common. During summer, the farmers lived in modest farmhouses, called *jasseries*. At springtime, the cattle was moved to grazing grounds at higher altitudes and moved back to lower elevations in fall (*transhumance*). At the beginning of the twentieth century, however, this system collapsed. The strong decline of the population density caused a strong decrease in grazing. Almost all *jasseries* became abandoned and fell into decay. In some parts of the subalpine zone, grazing stopped completely. In other parts, the way of grazing changed: the flock did not roam freely over the *hautes chaumes* anymore, but was kept in movable fences. Besides, farmers switched to sheep instead of cattle (Schaminée and Meertens 1992; Schaminée 1993).

This traditional system of pastural (cattle-lease, *bail à commande*) and mountain meadow land use developed during the late Middle Ages. It was a win-win situation for urban people and local farmers of the Massif Central. Urban capital was invested in cattle and the owners received agricultural products. The farmers produced meat, leather and other agricultural products, in particular cheese (fourme), and had little risk caused by unfavorable weather conditions. Like in other mountain regions used as summer pasture, the period of grazing lasted a couple of months until August. The number of domestic animals and the period of grazing was limited by strong regulations. Pastures were used on common ground, farmhouses and meadows were private property (Damon 1972; Schaminée 1993). Such grazing regimes supported high landscape heterogeneity in space and stabilized rich regional species pools.

Figure 3 shows a plan of the small farmhouses, called *jasseries* (Schaminée 1993, after Damon 1972). The largest part was composed by small stables for animals, the smaller part served as living room and place for cheese production. The concerted use, interplay and irrigation of water, dung as fertilizer for hay meadows and hay as fodder is described in Schaminée (1993). This agricultural system proved to be sustainable for many hundreds of years.

The importance of a constant management was already stressed by Josias Braun-Blanquet in 1926 in a study on mountain heathlands in the Monts du Cantal. The large-scale changes in land use during the twentieth century have strongly influenced the original diversity and vegetation pattern. An overall extensive grazing regime has

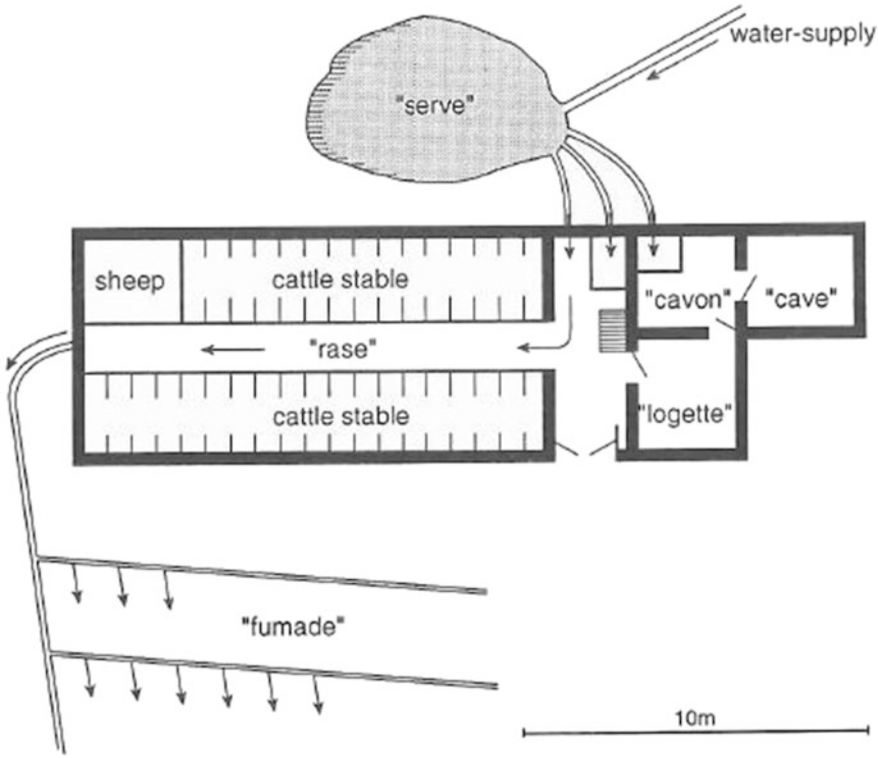


Fig. 3 Ground plan of a jasserie and its surrounding, at Garnier in the eastern part of the Monts du Forez (Schaminée 1993, after Damon 1972)

been converted into abandonment on the one hand and intensification on the other. Especially the mesotrophic mountain meadows near the jasseries, a unique feature within the oligotrophic and extensive heathland landscape of the subalpine zone of these mountain ranges, are showing a strong decline in floristic diversity. In this respect, these meadows, syntaxonomically to be assigned to the alliance *Polygono-Trisetion*, are no exception, as can be concluded from the voluminous documentation with regard to this subject (e.g. Klapp 1965; Dierschke 1991; Daniëls et al. 1987).

3 Eternal Rye Cropping in the Northwest European Lowlands

On the higher sandy soils in the northwest European lowlands, an age-old agricultural system was practiced for many centuries, the so-called *Potstal system*. An—also literally—central position hereby was taken by elevated field complexes,

Fig. 4 The Orange Lily, *Lilium bulbiferum* (photographed by J.HJ. Schaminée)

depending on the region called (in the Netherlands) *essen*, *enken* or *engen*. These were large complexes, located in the immediate vicinity of the farms, which were surrounded by vast heathlands. The heath had two important functions: first as grazing grounds for the flocks of sheep, who returned home in the evening and spent the night in the so-called *potstal* (potting stable), and furthermore as a supplier of raw plant material that was spread in the stable to be mixed with the sheep's faeces. The resulting fertilizer was then spread on the fields, where grains and other crops were grown. Due to the mineral components, these fields became higher and higher, and in this way they are still recognizable as elevations in the landscape today.

Rye (*Triticum secale*) was an excellent cereal to cultivate on these fields, as the species is able to grow on acidic sands that were too poor to grow other cereals. Cultivated Rye derived from the wild species *Secale montanum* and *Secale vavilovii*, which are endemic to forest clearings and field margins of South Asia, up to 2500 m above sea level (Schlegel 2014). The fields are known as eternal rye fields, but this image has been nuanced in recent years: the use was much more varied and in any case, they turned out not to be eternal. All sorts of annual herbals grew among the tall grain, many of which are now on the Red List of Vascular Plants in the Netherlands. Think of species such as *Arnoseris minima*, *Scleranthus annuus*, *Hypochaeris glabra* and *Anthoxanthum aristatum*. The latter species is called *slofhak* in Dutch, as the stalks of this grass contain a lot of silica, making the axes rapidly blunt (*hak* = ax, *slof* = blunt).

A rare and special plant species of these fields was the Rye Lily (*Lilium bulbiferum*; Fig. 4), which was well adapted to the original use. People used to plough the fields no deeper than about ten centimetres, while the main bulb of this species was growing at least 15 cm deep and thus spared during the process of ploughing. The fields are nowadays ploughed much deeper, and partly as a result of this, this beautiful lily has almost completely disappeared. At the initiative of a national initiative, called the *Living Archive*, an Action Plan is currently being worked out in collaboration with the province of Drenthe and a large number of organizations involved to preserve this characteristic plant for the Netherlands. Within this platform, programmes will be set up for both genetic rescuing and reintroduction of a wide range of priority species, a National Seed Bank will be established, and for each target species, a tailored plan will be set up. Among the target species there are many weeds from arable land. The *Living Archive* operates conform a stepwise approach, including: (1) analysing habitat characteristics of still-existing populations across the Netherlands, (2) assessing viability of these populations, (3) identifying new suitable sites by comparing them to habitat characteristics of viable populations, (4) collecting seeds from suitable source populations, (5) multiplying plant material through an *ex situ* breeding program, (6) using viable off-spring for reinforcing existing impoverished populations and/or reintroducing the species at former sites where the site conditions have been improved, and (7) monitoring the reintroduction success (Schaminée et al. 2019).

Because of the change in agricultural practice, the species has disappeared from the fields, but is still present in single places in gardens. For a long time, it was thought that the Rye Lily in our country was not native, but had managed to establish itself in the fields from gardens, but the story is exactly the other way round. The plants in the gardens originates from the fields; the plants were so beautiful that they were dug out in the wild and placed at home. The plant material that is still present is authentic and autochthonous and can serve as source material for the intended reintroduction. On the famous triptych of Hans Memling (from the fifteenth century), the Rye Lily is the last plant that the blissful can see at the foot of the stairs before entering heaven.

The two examples also demonstrated the major challenges nature conservation in rural areas is facing in the moment, at least in Europe but also in other parts of the world: on the one hand intensification, on the other hand abandoning. In European lowlands, especially in the densely populated northwest, intensification leads to a dramatic drop of biodiversity on the sites under management, whereas in European mountain ranges (as well as is in large parts of Eastern Europe, where traditional agricultural survived for many centuries but now (after the collapse of the communism) is rapidly replaced by modern techniques and the huge increase in applying artificial manure to increase the production. The dramatic changes in mountainous areas was perfectly predicted more than 25 years ago in a study on the landscape ecology of the Solano Basin in Tuscany, Italy, with the provocative title *Vanishing Tuscan Landscapes* (Vos and Stortelder 1992).

4 Agricultural Tapestry

Biodiversity and agriculture are entangled in an everchanging choreography. Some of the world's most remarkable species have evolved through agriculture, or found their habitat in man-made ecosystem; on the other hand, the ongoing development is turning now to be a growing threat for the same species. Local processes can have global consequences and vice versa. Questions arise such as: how are world processes affected by agricultural land use, what is the origin of species that are accommodated in agricultural ecosystems, what is the relationship between agriculture and nature, regarding different levels of farming.

4.1 Agriculture and Its Global Impact Over Time

Recently, the topic of deforestation has re-entered news headlines, also in the public debate. The clearing of rain forests in the Amazon area, as an example, on behalf of wood production and the construction of palm oil and soy fields has given rise to political conflicts. On the other hand, the call for reforestation or cultivating trees, to combat the growing CO_2-emmissions is also heard more often and more loudly. This entanglement of agricultural activity and climate can be recognized throughout history. Deforestation in order to increase hunting grounds in Northern America or (later) giving room for agricultural land use in Eurasia had its impact on local and global climate, which could be recognized in our common history.

At the same time, agriculture activity has always been driven by climate. As such, the climatic conditions and in line with the development of agriculture, have dictated history, as can be shown by a European example. In the pre-roman era, the central Italian area had a favourable climate for the cultivation of wheats, supporting the growth of the populations and the Roman society. However, a shift in climate conditions with increased drought in the central Mediterranean led to a decrease in yields and eventually in food shortages. This forced the roman people to expand their territory to the West and East, where conditions were more favourable. An empire was born. A few centuries later the coin flipped and a less favourable climate in Western and Eastern Europe forced the peoples living there to move. The Migration period started leading to the fall of the Western Roman empire (Harper 2017).

Climate, however, is not only a driver but can also be driven by man. In the middle ages, the European population flourished and the need for nutrition and building material peaked. The feudal system of land tenure, in which rights to farming were given in exchange for fealty, increased the deforestation in Europe. This is correlated with an increase in carbon dioxide in the atmosphere. The medieval warmth period is associated with a peak in CO_2 as was reconstructed from captured air in centuries-old ice cores taken from the ice caps. As the plague struck the European societies, leading to a decrease of 60% in population, spontaneous reforestation occurred. This is again associated with a decrease in atmospheric carbon. The Little Ice-age followed, resulting in a cooler climate throughout the seventeenth, eighteenth and nineteenth century, just until the industrial revolution gave rise to an unprecedented increase of carbon emissions (Soon and Baliunas 2003).

Current climate change will have an impact on agriculture in the near future. A growing world population increases the need for food, although area suitable for agriculture is in decline. In Asia and Africa, rice production, a crop feeding over 20% of the world's population, is threatened by an increasing number of climate extremes. Major production areas are found in low-lying lands and deltas in Bangladesh, Myanmar, Vietnam, Japan, and Egypt. Sea level rise and extremes in precipitation increase the risk of flooding plantations, leading to an estimated loss up to 20% in some countries before 2080 (Chen et al. 2012). The combination of a rising sea level together with the occurrence of more droughts leads to salinization of soils, decreasing the extent of rice yields. As it takes 2.000 l of water to produce 1 kg of rice, droughts in particular are forming a major threat. The same accounts for wheats, corn and potatoes. However, as the equatorial climate becomes more dry, a shift of these agricultural systems to higher latitudes is halted by other environmental conditions. For example, the dry and grassy plains of Siberia are not likely to support the growth of potatoes, rice or wheat, as the seasonal climate here becomes extreme. In addition, the vast areas of peaty soils of melting permafrost are no option for regular crop cultivation. As grasslands remain to dominate these areas, the area in which crops can be grown is diminishing. Still the need for nutrition grows. As the grassland systems in Eurasia are still able to support cattle and livestock breeding, the consumption of meat may become an increasingly inevitable alternative. An alternative that will further increase the pressure of climate change and environment change.

Let us return to the clearing of rain forests in the Amazon area for the construction of soy fields, to show the complexity of such global issues. Already in 2006, the Netherlands (one of the largest soy importers of the world) declared the Amazon to a no go area for commodity traders and processers. It was decided not to purchase products from areas in the Amazon that have been deforested after 2008. As a result, the soy production shifted to other areas in Brazil that were less protected, such as the savannah area of the Cerrado. Another escape was found in the likewise less protected forest areas of Paraguay, Bolivia and Argentina. In response to this, the Dutch government decided, in 2015, to restrict the import of the product to soy that meet the strict standards of the Round Table on Responsible Soy (RTRS), an international collaboration between governments, retailers and producers. Again, there is a snag in the grass. The strict rules only apply that the soy that is used for the production of meat, eggs and diary for the Dutch market, not for the products that will be exported. Within the context of this, it is a sad prospect that in Brazil, Paraguay and Argentina, still 110 million hectares of forest are registered to be cut legally, a staggering 20% of the entire amazon area (*De Volkskrant*, 31 August 2019).

4.2 The Origin of Species Living on Arable Land

An interesting question concerns the origin of weeds on arable land. Historical-geographic research has shown that the species in question all have their own story, as was already demonstrated by Tüxen in 1958. Charred seed residues from the German Rhineland showed that species such as White Goosefoot (*Chenopodium album*), Black Bindweed (*Fallopia convolvulus*), Redshank (*Persicaria maculosa*) and Hairy Vetch (*Vicia hirsuta*) were already present in cultivated fields from about 5000 years BC, in plant assemblages that were described as the *Bromo-Lapsanetum praehistoricum* (Knörzer 1971). A number of arable plants derive from nearby natural ecosystems, such as scree vegetation on mountain slopes, pioneer vegetation on riverbanks, and natural forest fringes. The name-giving Nipplewort (*Lapsana communis*) of the plant community mentioned is an example of the last group. Quite some species were present as local wild plants in human-affected environments before cultivation took place; with the establishment of systematic farming, they evolved into weeds or functioned as weeds without further evolution (Snir et al. 2015). Most species, however, originate from naturally appearances much further away. They mainly derive from a vast area from the Iberian Peninsula to West Asia, far more extensive than the 'fertile crescent moon' of Southwest Asia, where arable farming has its origins (Weeda et al. 2003).

Due to strong selective forces on agricultural land, crops and weeds may co-evolve a process that has been described and discussed in many scientific papers (Baker 1974; Radosevich et al. 1997; see Guglielmini et al. 2007 for a debate). A well-known example is the occurrence of specific weeds in flax fields, plant species that are hardly found outside these agro-ecosystems, making them vulnerable. In the Netherlands, for example, species like Flax Field Ryegrass (*Lolium remotum*), Flax Dodder (Fig. 5, *Cuscuta epilinum*) and False Flax (*Camelina sativa*) have all become extinct after the collapse of the flax cultivation in the fifties last centuries. The occurrence of coevolution is also demonstrated for crops and their rust fungi, and again flax provides a nice example, which already has been described by Flor in 1955. He discovered that genetically different strains of the fungus could only infect specific lines of flax, on which observation he concluded that the parasite and its host had complementary genetic systems as a result of coevolution (Kliman 2016.)

4.3 Industrial Agriculture

As the need for nutrition and convenience is growing worldwide, the efficiency for agriculture is increasing at an unprecedented pace. To counter effects of environmental change and responding to a growing demand, more land and new technologies are developed and applied worldwide. International development and agricultural land use are intertwined and particularly visible in East and South Asia and the Middle East. As an example, a consequence of a growing demand of

Fig. 5 *Cuscuta epilinum* (Universal History Archive/Shutterstock)

agricultural products is the use of artificial fertilizer (Fig. 6). Although it creates an increased fertility and more production on poor soils, the added nutrient cause a decrease in biodiversity as competitive species take over (Bobbink et al. 2010; Ceulemans et al. 2014). Where innovative techniques in Western society cause a decrease in artificial fertilizer consumption per hectares, developing countries are adding a growing amount of artificial fertilizer each year (FAOstat 2019).

Moreover, as most agricultural enterprises are embedded in a competitive and commercial system, where profits are driving the increase in efficiency and

Fig. 6 The global growing consumption of artificial fertilizer in kilogram per hectare of arable and permanent cropland (source: The Worldbank—IBRD-IDA 2019)

production on a global market, the technological advances in agriculture are continuously pushing the possibilities. Genetic manipulation is often inherent to selective breeding techniques. Genetic properties of species are recombined on a global scale to counter environmental threats, increase yields or to make the crops commercially more attractive. Having the lead in agricultural techniques improves the competitive position of farmers and pushes them to strengthen their position on a global market. Particularly in western society, the agricultural systems have been pushed over their environmental limits, which led to unsustainable farming that on itself has a demand of natural resources, which the land cannot provide. Resulting in pollution, hypertrophy and land depletion. At the same time, farmers that are outcompeted abandon their lands or are forced to use outdated and often polluting techniques and products.

As environmental problems are becoming more apparent, agricultural legislation in regards to pesticides, emissions, food quality and land use in western society are becoming more strict. This is not only leading to tensions between farmers and society (as farmers' competitive positions are threatened), but it also forces farmers to expand their activities abroad. Intensive and large-scale farming by western European farmers in Eastern Europe and Northern America strongly increased over the last decades often at the cost of local small-scale farming (Deininger and Byerlee 2011).

As agricultural products are sold worldwide, an increase in transportation (and its environmental consequences) have rapidly increased. As an example, the US state Iowa alone transports a yearly 152.6 million tons of agricultural products by train (a revenue of 6.1 billion US dollars). On a total, the United States export 33% of its agricultural products abroad for circa 190 billion dollars. Where to US has about 22.6 million hectares of agricultural area, the Netherlands is the runner-up in export of agricultural products (Figures of 2015). With a production area of 2.2 million hectares, the country exports for 115 billion dollars of agricultural products (a revenue that is six times higher per unit of surface area compared to US production), while the competition for export is growing internationally (CBS and WUR 2017; FAOstat 2019).

As small-scale agriculture has had positive effects on biodiversity. In Europe, biodiversity even showed a peak in species richness in the mid of the nineteenth century (Haveman et al. 2009), when a wide spectre of small crop-fields, forests, and meadows covered the countryside. Large-scale agriculture has opposite consequences. The lack of habitat diversity, environmental gradients and landscape connections are detrimental for biodiversity. The use of pesticides only strengthen this effect. A growing number of studies show a massive decline in insects over the last decades. Not only the number of species of insects decreased, also the total number of insects is in strong decline. Up to a 75% loss of insects was reported in heavily cultivated Netherlands and Western Germany within 30 years (Hallmann et al. 2017). The use of neonicotinoid pesticides, which is only part of its cause, has its legacy as the now-banned poisons were accumulated in the food web, probably led to a massive decline in insectivorous bird species in the same region in the same period. As insect populations disappear, also the services they provide for agriculture are under threat. Wild pollinators are essential for the production of 35% of our crops, of which amongst are 121 different bee species on a global scale (Klein et al. 2006).

As the world population is growing and the development of second and third world countries is gaining pace, the global intensification of agricultural lands is persistent.

5 Turning the Tide

The growing global demand for nutrition, space, natural resources, the threats of climate change, soil depletion, pollution and biodiversity decline underline the need for a different approach in our land use and agriculture. A tremendous amount of studies shows that biodiversity is a key factor in maintaining agricultural production. Climate resilience, crop health, pollination, soil stability and crop yields are all linked to local biodiversity. Therefore, to ensure food security in the future maintaining and supporting biodiversity should be a focus in the development.

5.1 Scaling Down

Large-scale intensified and internationally orientated agriculture, where an acre of land is forced to produce a yield, which demands many times more natural resources than an acre, can deliver, leads to land depletion and biodiversity loss. Added to that are the disadvantages of international transport (emissions) and the waste of products through this supply chain. Up to 75% of the fresh product are lost before consumption in the US. This loss is explained by a 7% loss during harvest, after which 33% is lost in transport or rejected upon arrival at processing facilities. During the production of end-products another 39% may be considered lost. About 10% of the products is rejected or marked as waste by retailers before the products reaches the consumers. And at that level, about 25% is not consumed in the end (Stroecken 2017). With a more efficient supply chain only a quarter of production is thus necessary to respond to the same demand. A large part of this supply chain is the transportation. Scaling down productions to local markets may increase efficiency, decreases production demands, decreases waste and decreases environmental impact.

5.2 *Organic Farming*

Organic farming is defined as a form of agriculture in which no synthetic inputs take place, such as artificial fertilizers, pesticides or hormones (Rehber et al. 2018). With over 69 million ha, almost three million farms and a revenue of more than 90 billion euro's worldwide, organic farming is one of the fastest growing agricultural disciplines in the world. Growing 5% per year globally, organic farming seems to be linked to an increase in general welfare. Switzerland and Denmark are spending most on organic products per capita. As more area is in need to produce equivalent yields, organic farming generally requires more space. To counter the absence of pesticides, other methods of crop cultivation are in need. Old traditions like crop rotation or newer methods such as strip cropping, to prevent depletion of soil nutrients, offers the chance to produce multiple crops and meanwhile increase the biodiversity on a farmland. Additionally crops are less prone to pests (Li et al. 2014).

Wild collection is often considered as part of organic farming. Over 440 products are known to be commercially picked or collected from their ecosystems. The area where wild organic farming is practised is estimated to be almost 40 million hectares in size, spread out over 71 countries. In this extreme form of organic farming, the ecosystem plays a central part and an ecosystem conservation approach is necessary to maintain yields over longer periods. A good example of this is Wild Rooibos tea. The leaves for this tea are picked from the Rooibos shrub (*Aspalathus linearis*) which only occurs in the Fynbos biome in the southwest of South Africa. Where cultivating outside of its natural distribution area is impossible, even small organic plantations are devastating for the vulnerable ecosystem. The indigenous Koi-San peoples, as an alternative, collect Rooibos leaves from the original vegetation, meanwhile protecting their environment and culture. However, the limited yields, the small market as well as the immense competition makes wild Rooibos farming hardly profitable until now (Sluiter and Schaminée 2012).

Organic farming is marketed around the world as a durable alternative to conventional farming, provided that farming methods are further developed. However, definitions, legislation and especially certification is often not clear and therefor often misused by large producers and retailers.

5.3 Paludiculture

An example of innovative agricultural practice is farming on peatlands. Historically, peatlands were considered unusable for crop farming, due to wet conditions and the low fertility. Large areas of peatland were therefore either exploited for their peat as a fuel or drained and transformed into still inefficient cropland, grazing areas or forest plantations. With the destruction of peatland, carbon emissions increased as oxygen caused large amounts of organic mass—accumulated through centuries under anoxic ad wet conditions—to decompose. As this led to an ongoing chain reaction, the loss of peatland led to more peat loss. This also leads to land subsidence in peatland around the world (Pronger et al. 2014), often with severe consequences for inhabitants of these areas, who need to coop with structural damage of buildings and increased impacts of weather extremes and sea level rise (Gambolati et al. 2005).

Paludiculture may offer a good alternative. Here well-adapted crops are grown on wet soils. By rewetting peatlands, both soil subsidence as well as carbon emission may be halted, even turning the system into an efficient carbon sink with a rising soil which may even counter problems caused by sea level rise, salinization and extreme drought events. Current research programs are focussing on the cultivation of crops as sources of biomass and building materials such as reeds, moor-grasses and peat mosses (*Sphagnum*) or even, through forestry, alders for application in cardboard, paper of isolation material. But also edible crops may be cultivated through paludiculture in the future, such as Wild rice in Northern America. In addition, due to climate change more peatland will become available. Peat, which is stored in permafrost, will start to melt and decompose under rising temperatures. Rewetting these systems may limit the effects of permafrost loss and may compensate losses of agricultural lands on a global scale.

6 Concluding Remarks

As the global population grows, the need for food security increases. However, the depletion of resources and the immense impact agriculture has on our world's landscapes, climate and biodiversity is beginning to reach its limits. Therefore, new ways of agricultural practice is necessary to ensure our future: a form of agriculture in which nature and farming are much more interlinked and where the resilience of food production relies on the capacity of our natural capital to coop with the increasing threats of climate change and urbanisation. Therefore, we need to protect our current biodiversity. New approaches such as multifunctional land use, where cropping and nature conservation go together, are interchangeable or even support natural ecosystem functions. Ecosystem functions, such as natural pollination of crops, need to be protected. The genetic capital that incorporates the adaptations to climate change is already present in our nature and should be protected. Production and food supply chains can become more efficient, so production does not need to increase further and also the natural capacity of cultivated soils should be taken more into account to ensure food production in the future.

Agriculture and climate dictated our societies' history. As our population and our need for products grows above our planet's capacity and the repercussions become more visible, we need to start to overthink our production systems. Agriculture can take the lead in a changing world. We need to stop focusing on quick wins and maximal productions, but change our perspectives to long-term food security and resilient nature-based food systems. In this way, agriculture can also lead us into the future.

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Urban Habitats: Cities and Their Potential for Nature Protection

Jan Jansen and Carsten Hobohm

Abstract What can cities do to harbour and promote wildlife, to support nature conservation and environmental sustainability, and also to improve people's relationship to nature, both by direct interventions and by education/communication?

To answer this question a few main lines are followed and linked to each other. These include (1) natural history, (2) ecological aspects, (3) nature management, (4) attractiveness of nature and the affinity to nature, and (5) future perspectives. We reviewed publications relating to three broad scientific disciplines as applied in current urban ecology, namely: (1) natural sciences, (2) engineering/urban planning, and (3) social sciences.

The relationship to nature including urban climate, urban biodiversity and land use, is important for the whole urban life including health. To improve that relationship, it is necessary to have the support of citizens for policies of biodiversity management and protection. This is a promising development; however, in many cases the use of indigenous species and the acceptance of spontaneous developments in vegetation and wildlife within urban areas is hardly getting underway.

Cities are agglomerations of artificial constructions and humans tolerating little space for wildlife. Nevertheless, by use of horticulture, greening of roofs and walls, and species conservation programmes, cities and urban areas can play an important role for wildlife and the survival of rare species inside and outside urban regions. Because of the heterogeneity and the diversity of habitat types which they offer, cities—certainly in intensive farming regions—are regularly more species-rich than comparable rural areas in the surroundings.

Thus, spontaneous natural processes in urban areas should be allowed as much as possible, under conditions such as the safety of citizens and the control of invasive and exotic species. Then, evolution can progress even in urban environments at the

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interface between natural and cultural processes. In addition, spontaneous natural processes in urban areas give city dwellers the opportunity to experience nature from nearby and to feel connected to natural processes, as happened in the pre-urban past.

Meanwhile, botanical gardens, aquariums and zoos play a vital role for the survival of rare species. Most of the larger institutions are located in cities, where they have more visitors than the ones located in rural areas. Thus, such institutions in cities have a high value for the exchange of information, including education for schoolchildren, simply because of the proximity.

Keywords Urban wildlife · Botanical garden · Zoo · Aquarium · Affinity to nature

1 Introduction

Consumption of global resources and the anthropogenic transformation of the biosphere are increasing. The existence and growth of cities are directly linked to the production and trade of energy, resources and food, and to the damage of ecosystems, far away from the cities (Cieslewicz 2008; Day and Hall 2016; Riffat et al. 2016; Simon 2016; Wolfram 2016; Torrey 2004). Cities meanwhile harbour more than half of the world's population, concentrated in coastal regions and in temperate, sub-tropical and tropical climates.

Sustainable development at local to global scales depends upon the pathways taken by cities in the near future (Wolfram 2016). Urbanisation and cities can be major threats to global sustainability (Simon 2016). But they can also play a key role in the transition to global sustainability, being areas where greening and nature conservation can easily promote better conditions of life for both humans and many other biota.

For millennia, humans have survived by hunting and gathering in migratory groups, foraging in the wild nature. These groups changed into sedentary societies as a result of their ability to domesticate plants and animals (Neolithic Revolution). The Industrial Revolution allowed the human population to rise exponentially. Today over half of the human population lives in urban areas, and pure wild nature has been minimized. In just a short period, man's life has changed dramatically. Previously, he lived among plants and animals and had an intense relationship with nature as a whole, while now he spends large parts of his life between the bricks and concrete of built environments. His urban habitat is alienated from its origins and now accommodates areas for foreign ornamental plants in gardens and parks. Common fauna includes domestic animals such as dogs, cats, honey bees and homing pigeons. Nevertheless, many wild plants and animals have changed into synanthropes and have spontaneously found niches and habitats in these urban areas, even though in many cases cultivated ornamental plants and hobby animals are more prominent. Synanthropes live near, and benefit from, an association with human beings and the somewhat artificial habitats that people create around them. Depending on the intensity of human activity, plant species and animals of the original ecosystem can be replaced by synanthropes including less sensitive native species (apophytes) or alien (anthropophytes) both in urban areas and in rural areas (Early et al. 2016).

Spontaneous nature in the city is of great consequence for the preservation of niches for native wildlife, even though non-natives are often in the majority. Spontaneous natural processes in the city are important also in adaptation and speciation, a sort of evolution in the urban jungle (Schilthuizen 2017; Thomas 2017). Not being subjected to the intensive levels of management and pesticides used on farmland, urban areas can support locally, nationally and even internationally important biodiversity that is struggling to persist in the wider countryside (Connop and Nash 2018). Of even greater importance, in our view, is the opportunity for the city dweller to interact with free nature as people did in the very distant past. For in this way, people can come to support policies for stopping the decline of biodiversity in the countryside. Additional green areas in cities created for leisure such as parks and botanical gardens could better focus on accommodating indigenous species with an additional emphasis on endemic species from the region (wildlife parks, nature gardens). Native plants can support native insect and fungal populations better than many ornamental plant species.

Cities are breeding grounds for innovation and urban residents often have much influence on political and socio-economic issues, as cities host most of the administration, markets, capital, culture and consumers. On the other hand cities also destroy nature. In addition, cities depend on resources and ecological services from distant ecosystems, and this has a huge impact, with the result that very little is left of Earth's remaining wilderness both terrestrial and marine.

The surface of the Earth can be subdivided into ecoregions. City authorities could be made responsible for the biodiversity of the ecoregions in which they are located. They could be given the task to stop the decline of biodiversity, not only within their administrative boundaries but also in more distant areas within the entire ecoregion. Cities could be a driving force in stimulating the experience of nature not only with ornamental plants in parks or trees along streets as the usual practice is, but also by offering natural beauty in the vicinity, by displaying natural vegetation in botanical gardens and parks, by allowing spontaneous plant dispersal in public places under specified conditions, also by promoting nature education and research, and ultimately by setting rules for nature protection.

This contribution offers a few examples of projects in a few cities throughout the world, which illustrate promising steps.

2 Urbanisation and Its Consequences for Plant Ecology

Habitat is generally defined as the environment in which a species lives. It is characterized by both physical and biological features. At first the concept of habitat was used only for a single species (the autecological approach), while biotope was used for an assemblage of plants and animals (synecological approach). Today, habitat is generally used synonymously with biotope, so that the biotope of a community is also called its habitat, (see for instance the Habitats Directive of the European Union). The widespread use of the term habitat in biology goes back to Linnaeus (1753) who in Latin described the occurrence of a species with habitat in . . . ("Lives in . . .").

Observations and interpretations of ecological interactions extend back to the origins of science and have early Greek origins (Egerton 2001). However it is not until the nineteenth century that ecology would be recognized as an own scientific discipline. In those days, humans already interfered with many ecosystems, but remained largely excluded as subjects of ecological thinking and experimentation (Alberti et al. 2003).

The first urban habitats developed before and during the Neolithic Revolution when the domestication of various types of plants and animals started to transform nomadic hunter-gatherer groups into sedentary societies based in permanent built-up settlements. The impact of man on ecosystems increased and other kinds of human-induced habitats evolved, often at the costs of forests (Roberts et al. 2018). However, from the development of the earliest fortresses and cities during the Neolithic Revolution until the Industrial Revolution, there was a fairly stable equilibrium. On the one hand there was a relative large human population in a rural context of semi-natural and natural habitats, living mainly on subsistence farming. On the other hand there were small populations centered in relatively safe villages and towns, living on jobs, trade, and taxes. Small markets, tiny family businesses, administration, an occasional garrison, symbolizing the centre of power, provided jobs and order (e.g. Davis 1955; Grauman 1977). Synanthropic plants and animals developed in the evolving urban habitats (Sukopp 2002; Wittig 2004). Non-indigenous plant species introduced in Europe prior to AD 1500 are named archaeophytes, while post AD 1500 alien species are named neophytes. Native species that could invade the new habitats, including the urban ones, are known as apophytes.

The year AD 1500 marks the discovery of the New World and the Columbian Exchange that caused the widespread transfer of plants, animals, diseases etc. which invaded the natural, semi-natural and man-made habitats (Nunn and Quian 2010). In the pre-industrial era, limitations on technology and on the availability of food supplies, coupled with widespread diseases in urban settlements, imposed a natural ceiling on urban population growth, and hence on urbanisation (Fox 2012). An example is the balance between economy and ecology of heathlands in Europe (Diemont et al. 2013). The heathland-based economy and the associated habitats endured for some 5000 years, until in the nineteenth century a significant increase in jobs in urban areas (as a result of technological innovations) put pressure on agricultural productivity. Then, new land-use forms started changing the countryside (Haaland et al. 2004). Larger settlements developed, especially in areas with a range of habitats that provided opportunities for a variety of land uses (Luck 2007). It is therefore not surprising that many towns and cities were originally situated in areas with a relatively high biodiversity (Kuhn et al. 2004; Ives et al. 2016). The economy in such areas was originally largely based on the opportunities offered by the topographical location and by the surrounding ecosystem (e.g. Jansen et al. 2013).

In those days, citizens were often entangled with the life that surrounded them (Rupprecht 2017). They interacted with nature, although alienation from nature had already been noticed. Since the Middle Ages, a utilitarian culture and land use had become rather dominant. The idea that wildlife had an intrinsic value was simply absent during this period. In the nineteenth century, Romanticism—the discovery of the landscape, admired and pictured by man (Westhoff 1983)—arose as counter current in response to the Age of Enlightenment.

With the onset of the Industrial Revolution in Britain by the late eighteenth century, the ratio rural-urban population started changing as people moved from the countryside to the urban areas that offered jobs. In spite of the decrease in rural population, the loss of semi-natural ecosystems in the countryside accelerated because of intensification of agriculture (monocultures) and forestry (monocultures, forest fires), On the other hand, abandonment of the countryside gave opportunities for nature development (ELO 2009). At the time of the Industrial Revolution, the number of neophytes increased as a result of the expanded traffic and trade through modes such as railways and steam ships (Wittig 2004). The next phase was the fast growth of cities in the twentieth century, which triggered an even larger influx of neophytes (Wittig 2004). At present the average flora of cities in Central Europe consists of 60% native species, 15% archaeophytes, and 25% neophytes (Pyšek 1998).

The percentage of the population living in urban areas around 1800 is estimated at 21% for Western Europe, clearly higher than, for example, 4% in Central-Europe, 6% in USA and 7% in the world. These percentages increased respectively to 41%, 19%, 40% and 16% in 1900; to 61%, 35%, 64% and 29% in 1950, and to 75%, 60%, 79% and 47% in 2000 (Klein Goldewijk et al. 2010). In 2018, the most urbanised regions included Northern America (82%), Latin America and the Caribbean (81%), Europe (74%) and Oceania (68%). Today 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 (United Nations 2018). A considerable part, often including megacities and conurbations, is located in coastal zones (Small and Nicholls 2003; Von Glasow et al. 2013). However, it is expected that most growth will take place in small and medium-sized cities (Secretariat of the Convention on Biological Diversity 2012).

Urbanisation represents a human ecological transformation which implies a huge shift in the spatial and material relationships of humans with the rural and natural world (Rees and Wackernagel 1996). Also, urbanisation contributes to the loss of the world's biodiversity and the homogenisation of its biota (Aronson et al. 2014).

This is intensified by the choices which people make for planting in gardens and parks. The choices are motivated by visual impact or ease of management, and have typically favoured horticultural cultivars over native species. These actions can diminish the value of urban green spaces for biodiversity as they become characterised by a small range of introduced, frequently non-native species that can tolerate the anthropogenic conditions (McKinney 2006, 2008). These practices have created urban ecosystems which are structurally and functionally similar across bioregions, and which are distinct from local native ecosystems, but which are similar to each other, a phenomenon called urban biotic homogenisation (McKinney

2006; Groffman et al. 2014). This generic approach to urban greening constitutes "blandscaping": landscaping that uses the same designs, and often the same species. It has become a "best practice" model that has been shared and used across different urban regions nationally and globally (Connop and Nash 2018).

A similar homogenization, albeit with a different driving factor, can be seen in the farmed countryside over many parts of the world. For instance The Netherlands, now one of the largest agricultural exporters in the world, used to have a rich wildlife in the countryside. The species richness and landscape heterogeneity, even in agricultural regions, were the result of fragmented ownerships in combination with mechanical land-use practices. The increasing use of mineral fertilizers and pesticides is a development of the last hundred years. Today industrial agriculture is more and more independent of the ecological conditions, as unfavourable conditions can be compensated by application of water, fertilisers, melioration, or other measures. Whereas historically each region had its own types of land use and could easily be recognized at the landscape level, now those regions look more and more the same as agricultural practices become increasingly similar. As a result, local flora and fauna become more and more homogenised. This process had already been noticed more than half a century ago by Westhoff (1949) who pointed out that this increased the scale, reduced the variation in the environment and led to a great loss of species. Because cities are interlaced with their surroundings, processes in the rural areas are affecting urban regions as well, and the declining biodiversity outside the cities will affect the cities as well.

3 Affinity to Nature

What are the consequences of urbanisation for the perception of the citizens and their attitude towards nature. Today, urban residents have much influence on political and socio-economic issues (e.g. McDonald et al. 2018). When there is sufficient support among them for environmental issues and for stopping the loss of biodiversity, there is hope for the conservation of nature worldwide.

Urban dwellers have different possibilities for getting in touch with the biosphere, such as theoretical learning, visiting museums, botanical gardens, aquariums and zoos, and even by direct contact with the wildlife in the city. Fascination by experience might be an important step. The occasion of experiencing next door nature in urban and peri-urban habitats may promote a positive nature-culture relationship.

Socio-cultural facilities and performances, such as painting, sculpture, storytelling, poetry, music, mindfulness, and so on, can support this relationship. Exhibitions of photographs can easily result in a wish for more contact with/knowledge about nature. Knowledge grows from the experience of nature and can also be transferred from one person to another: nature study and nature education. From the science of biology and ecology, and from insights following experiences of natural beauty and nature study, people can make choices, including what nature they want to preserve.

With millions of various person-nature relationships, based both on rationality and emotion—affinity—cities have a high potential for nature protection, manifested for instance in fundraising campaigns and in private investments in nature and nature conservation programmes. The affinity to nature, the extent to which individuals include nature as part of their identity (Schultz 2002), is linked to pro-environmental actions and a strong motivation for protecting nature. This link makes it important to investigate the affinity to nature (Frantz et al. 2005; Kaiser et al. 2008; Kals et al. 1999; Liefländer et al. 2013). Nature exposure and affinity to nature can have positive effects on physical and psychological health, social cohesion, crime reduction, environmental awareness, economic gain, and sense of belonging (Barton and Pretty 2010; Cervinka et al. 2011; Fuller et al. 2012; Giles-Corti et al. 2005; Howell et al. 2011; Mayer et al. 2009).

In those ways the majority of the world population is confronted every day with nature, charging their emotion and knowledge batteries to nature (e.g. Fuller and Irvine 2010). If most of the population were to experience this almost daily connection, it should be possible to cultivate the broad support of citizens for pro-environmental behaviour (Dearborn and Kark 2010; Karvonen and Yocom 2011), for example supporting the biodiversity and ecosystems goals of the 2030 Agenda for Sustainable Development (United Nations 2015).

4 Flora and Fauna of Cities and Urban Habitats

The land area covered by cities is estimated to be around 0.5% globally, with 0.67% in Northern America, 0.47% in Southern America and 1.78% in Europe (Schneider et al. 2009, 2010; European Commission 2010). According to NASA SEDAC (2011) based on GRUMPv1 data roughly 3% of the Earth's land surface is occupied by urban areas. These figures give an indication, but there is uncertainty because of the definition of urban area (e.g. Nowak da Costa et al. 2017). Yet when we take the figures as an indication, we could roughly say that over half of the world's population lives in 3% of the earth's land surface. But cities depend by far more on much larger surfaces of the earth including resources and ecological services from distant ecosystems (Wackernagel et al. 2006; Baabou et al. 2017).

Probably, almost all habitats in the world are influenced by long range effects of human activities and/or waste. Human interference is noticeable in many places. Very little is left of Earth's remaining wilderness, both terrestrial and marine (Allan et al. 2017; Jones et al. 2018). In Europe for example, less than one-fifth of the habitats and species have a favourable conservation status. Habitat types associated with agriculture have an even worse status (COM 2009; Janssen et al. 2016).

The degree of human pressure can be represented in several stages, with the extremes from natural via semi-natural to artificial. The biotopes in urban areas usually vary from semi-natural to artificial. Nevertheless, in most cities there are also small patches in parks, gardens, basements, and under roofs without access or traffic. Human activity is the decisive factor that alters, disturbs or completely destroys the original ecosystem, and the conditions of water, soil, air or climate (Walz and Stein 2014).

Even before the Neolithic period, some species may have followed human traces. In the following millennia their numbers increased slowly (e.g. Di Castri 1989). In the post-Columbian period, the pace of human-induced spreading of species increased (Kowarik 2003; Meyerson and Mooney 2007; Seebens et al. 2018). Since most urban areas have existed for less than 100–200 years, it follows that a large number, both of species and specimens, have only recently been confronted with urban habitats (e.g. Hulme 2009; Humphries et al. 2019). The question arises how quickly and widely flora, vegetation and fauna have been able to adapt to the new circumstances. This question is important, as cities might play a major role in contemporary evolution by accelerating phenotypic changes in wildlife, including animals, plants, fungi, and other organisms (Alberti et al. 2017; Rivkin et al. 2019).

The flora and fauna of a region or city is represented by taxonomic lists of the plant and animal species that occur in that area. Preliminary lists of plants and animals date back at least to the time of the Greeks and are from Theophrastus and Aristotle respectively. It can be assumed that prehistoric hunters and gatherers already knew much about species and the ecological conditions in their surroundings. The first extensive floras of urban areas emerged in the course of the seventeenth and eighteenth centuries, such as those of London, Paris and Berlin (Sukopp 2002). Wildlife knowledge and technological development enhanced and intensified human interaction with nature (Costanza et al. 2007).

The classification of European synanthropic vegetation distinguishes 10 groups of vegetation classes dominated by higher vascular plants, and in addition, a series of assemblages that consist of dominating bryophytes and lichens (Mucina et al. 2016).

Vegetation classes typical for urban areas include the class of subcosmopolitan therophyte-rich dwarf-herb vegetation of trampled habitats (Polygono-Poetea annuae) and the class of anthropogenic vegetation in human-disturbed habitats in the subarctic and Arctic zones of Russia, Siberia and North America (Matricario-Poetea arcticae). Other anthropogenic vegetation classes include Perennial (sub)-xerophilous ruderal vegetation of the temperate and sub-mediterranean regions of Europe (Artemisietea); tall-herb semi-natural perennial vegetation on disturbed forest edges, nutrient-rich riparian fringes and in forest clearings in the temperate and boreal zones of Eurasia (Epilobietea angustifolii); and annual weed segetal vegetation of arable crops, gardens and vineyards in the cool-temperate and boreal zones of Eurasia (Papaveretea rhoeadis). Also at lower rank (alliance, association) there are a number of plant communities which have their centre of gravity in urban areas. This also applies to a number of bryophyte and lichen assemblies. In addition, vegetation units which are assigned to other vegetation groups can also populate typical biotopes of urban origin. There are, for instance, a number of species which frequently grow on walls. This class is described as thermophilous chasmophytic vegetation of walls of the Mediterranean and the winter-mild atlantic to subcontinental regions of temperate Europe, Middle East and North Africa (Cymbalario-Parietarietea). Such urban wall vegetation comes in part from natural habitats of rock crevices and screes. Where construction is taking place and parts of the soil surface are open, ruderal vegetation (Artemisietea) usually occurs. Analyses of the complex urban-rural gradient shows that urbanisation filters species in communities depending on their adaptability to conditions in built-up areas (Cochard 2017). For instance, kitchen gardens in urban areas may host species of the class Papaveretea rhoeadis, but arable fields in rural areas host many more species. Epiphytic lichen and bryophyte communities in cities, towns and villages occur on various kinds of trees along streets, in gardens and parks. However, because of the reduced air-quality, the relating communities in cities are often relatively species-poor in comparison to lichen or bryophyte communities far away from cities and industries in less polluted regions.

All these communities support species of various origin: apophytes (native) and anthropophytes (foreign). Over time, both in the urban and in the rural areas, more and more non-native species have spread (Simberloff et al. 2013; Aronson et al. 2014). At least 3.9% of all currently known vascular plant species of the global vascular flora have become naturalized outside their natural ranges because of humans, approximately equalling the size of the native European flora (van Kluenen et al. 2015). A consequence of invasions is the possible decrease of native species abundances, or even their replacement by non-native species (Martin-Albarracin et al. 2015), although native species are not always threatened (e.g. Thomas and Palmer 2015). In general, neophytes may invade urban areas, but there they do not easily replace native species. But urban areas can function as a hub from where these neophytes can spread into the rural areas (Kühn et al. 2017). There is usually a gradient from very urbanised to very rural grid cells. In urban areas, there are specific niches where non-native plant species may thrive and where native species may be less competitive (e.g. Lososová et al. 2016). But outside the urban areas there is a multitude of habitats which are less impacted and which may host not only native plant species with a wider ecological amplitude but also with a small amplitude. In some cases, these rural habitats may host endemic plant species. Indeed, the effects of colonization of neophytes include homogenisation of both floras and habitats (Olden 2006).

According to Connop and Nash (2018) "historically, aesthetics and recreation have been the overriding drivers for urban green space design and management. This has led to the simplification of habitats through frequent mowing, pruning of trees and shrubs, removal of dead wood and mulching". Ecologically driven practices were not developed until much later (Wolschke-Bulmahn 1999). By selecting plants based on beautification and easy thriving, cultivars and exotics were favoured over native plants previously found in the original ecosystem. These kind of selecting practices have been and are still being applied all over the world, putting pressure on biodiversity and creating a kind of biotic homogenization of parks and gardens (McKinney 2006; Groffman et al. 2014). In short, in too many urban environments that lie in the same bioregion, one finds the similar immediately eye-catching cultivars and exotics. In countries with intensive agriculture and livestock farming, more and more species have come under pressure in rural areas. Today urban areas may offer better options for some species than the rural area where they originally thrived. Such urban sites can function as safe havens for specialist species that have been squeezed out from the rural hinterland (Denters 2020). Of course not all cultivars and exotics have to disappear from the streets, but isn't it obvious to take advantage of the better environmental conditions in the urban areas and try to free up places here for endangered endemic species from the rural areas.

For example, on the campus of the university and the academic hospital in Nijmegen (Netherlands) an attempt is made to answer the question what a company or organization can do to improve conditions on their terrain in order to accommodate the greatest possible biodiversity. A special way of monitoring is applied so that almost everyone can participate. A communication strategy is being developed in order to share experiences with all stakeholders including staff, students and visitors, making it clear that we as humans live among other species on this piece of earth. A bump of wood branches is not a mess, but a workplace for other species; such as an office is a workplace for the Homo sapiens (Van Gemert 2019).

In a small and flat and endemic-poor country as the Netherlands where the fraction of built-up area is over 15% (CBS 2012), an urban flora district or plant-geographical urban district can be distinguished. It consists of the larger city centres of the Netherlands, railway yards, industrial areas and other stony areas (Denters 1994, 1998, 2007). The urban district in The Netherlands has flora and fauna that are largely dependent on urban habitats. The Dutch urban areas are characterized by, among others, a relatively high temperature, resulting in a specific type of flora with a conspicuous high number of neophytes, mostly from warm and humid climates (Denters 2007). Urban warming favours C4 plants in temperate European cities (Duffy and Chown 2016). These species often originate from other regions. There is a counter-influence: green infrastructure can improve thermal comfort in outdoor urban spaces in moderate climates (Klemm et al. 2015).

The term *anthropogenic biomes*, also known as *anthromes* or *human biomes*, was first coined by Ellis and Ramankutty (2008). They identified eighteen anthropogenic biomes including dense settlements, villages, croplands, rangelands, forests and wildlands. They found that anthropogenic biomes clearly dominate the terrestrial biosphere, covering more than three quarters of the Earth's ice-free land and incorporating nearly 90% of terrestrial net primary production (NPP) and 80% of global tree cover (Ellis and Ramankutty 2008). More than 75% of the Earth's ice-free land showed evidence of alteration as a result of human residence and land use, with less than a quarter remaining as wildlands, supporting just 11% of terrestrial net primary production.

5 Cities in Ecoregions, Ecoregions Represented by Cities

The world can be divided into biomes that can be subdivided into ecoregions. Dinerstein et al. (2017) provide a map of the world's 846 ecoregions. The flora and fauna of cities in general is composed both of cosmopolitans that is species with a very large distribution in the related climate zone and of others that are restricted to the ecoregion.

Urban habitats usually contain buildings with rooftops, balconies, pavements, gardens, parks, cemeteries, railway stations, brownfields, and so on. All these are used not only by humans but also by wildlife. Species compositions of these urban habitats may differ significantly because of different climates, ecoregions, and use. Such differences may be even larger especially when these urban areas lie within the world's 36 biodiversity hotspots that are presently distinguished (Mittermeier et al. 2011; Critical Ecosystem Partnership Fund 2016).

The development and growth of urban areas has both negative and positive effects on the regional biodiversity because of the damage to the original habitats and the addition of artificial habitats. Compared to surrounding rural areas, cities have often lower biomass. However, with respect to the taxonomic group considered, the species richness may be higher, e.g. if comparing urban and non-urban richness of vascular plant or bird species in areas of the same size (Haeupler 1997; Ferenc et al. 2014; Ives et al. 2016).

According to Weller et al. (2018) there are 422 major cities (over 300,000 inhabitants), located in the Biodiversity Hotspots, 383 of which are expanding and disturbing the unique habitats and threatening the biodiversity of the Hotspot.

The flora and fauna of a city depends on the ecoregion where it is situated and on the habitats that are present in the given urban area, their accessibility for species (native, non-native) and the way these habitats are managed (Nilon et al. 2017).

In all 76 terrestrial ecoregions of North America, urban cover is positively correlated with both species richness and endemism. Conservation efforts in densely populated areas may be just as, or even more, important than preserving remote parks in relatively pristine regions (Ricketts and Imhoff 2003). However, urbanisation also often triggers the replacement of native or endemic species by already widespread non-native species, reducing spatial diversity (McKinney and Lockwood 1999; Sukopp 2003). In general, the number of non-native species increases towards centers of urbanisation, while the number of native species decreases (Sukopp 1997; McKinney 2002). This is no surprise because in general urban density decreases with distance from the centre of the city (Clifton et al. 2008). However, the well-being of city and region residents is affected by both the health and availability of resources and ecological services from distant ecosystems (Wackernagel et al. 2006), some of which are part of the ecoregion in which their city lies and some of the ecosystems from other ecoregions.

6 Species Conservation in Botanic Gardens, Aquariums and Zoos

The objective of modern botanical gardens, aquariums and zoos is much different from in the past. For example, monastery gardens were often used for the cultivation, study and use of medicinal plants. Nowadays, botanical gardens are often related to universities, and most of the large zoos and botanical gardens are located in big cities.

A relatively recent objective of the last five to six decades is to support species conservation and to increase cultivated and captive populations of extremely rare animal and plant species. The Jersey Zoo was established by Gerald Durrell (1925–1995) in 1959. Durrell thought that zoos primarily should act as habitats and regenerators of endangered species, and initiated spectacular projects to protect extremely rare and critically endangered animals. For example, in 1976 only four individuals of the Mauritius Kestrel (Falco punctatus) lived in the wild with one female. At that time, the Mauritius Kestrel was the rarest bird in the world. Gerald Durrell and a colleague removed eggs from the nests to breed the birds in captivity. They supplemented the diet of the wild kestrel so the birds were able to lay new eggs. Because some birds were bred in captivity and because the food of the birds in the wild was supplemented, the number of birds slowly increased. In 1988, 21 birds were reintroduced to the wild on Mauritius. Today the population of Mauritius Kestrel is estimated as 170–200 birds (see the IUCN Red List on the internet), unfortunately again with a declining population.

Today, botanical gardens, zoos and aquariums worldwide cooperate by exchanging animals, plants and knowledge about the management of species conservation, and about animal welfare and environmental conditions that allow plant populations to increase. Networks such as the Association of Zoos and Aquariums (AZA) or the European Association of Zoos and Aquaria (EAZA) are working together with the aim of protecting and supporting wildlife.

Since the beginning of species conservation programmes of zoos in the 1970s, various animal species have been saved from extinction. Furthermore, a few species have been reintroduced successfully into the wild (cf. IUCN Red List: iucnredlist.org). These include: Arabian Oryx (Phoenix Zoo), Przewalski's horse (div. zoos), California Condor (San Diego Wild Animal Park and Los Angeles Zoo), Corroboree Frog (Taronga Zoo in Sydney, together with other zoos), Bongo (div. zoos), Regent Honeyeater (Australian zoos), Panamanian Golden Frog (div. zoos), Bellinger Riverturtle (Taronga Zoo in Sydney), Golden Lion Tamarin (div. zoos), Amur Leopard (div. zoos).

Most of the large botanical gardens, aquariums and zoos in the world are located in cities. This means that many visitors can come in contact with species which only few people have ever seen in their natural environment. Guided tours and exchange of information might help to inform people and increase their interest. With money paid by visitors, members and sponsors, related programmes might easily be enhanced and expanded.

The following examples illustrate activities of different botanical gardens in the world.

Already in the 1920s 'educational gardens' were established in the Netherlands. They were later called 'heemtuinen' (wildlife gardens with native species from the region). The aim was to familiarise people with the wild flora and its visitors such as butterflies, bees and other insects (Thijsse 1941). A good example is found in Amstelveen, a suburban part of the metropolitan area of Amsterdam. A huge number of rare and endangered native plants grow there. City people can experience daily contact with the native flora.

A special form of the wildlife garden is the plant sociological garden which arose in Bremen and Hannover in Germany and later in Nijmegen in The Netherlands (Tüxen 1947; Westhoff 1954, 1971). Perhaps the most consistent one was the garden in Hannover, which aimed to bring together a large number of vegetation types that occur in the wider region. Unfortunately the garden in Hannover has ceased to exist, but the garden in Nijmegen still exists, albeit in a reduced state. The model is interesting, as plant sociology (including classification of vegetation types) forms the basis of the description of Natura 2000 habitat types in Europe. The botanical garden in Nijmegen hosts several examples of Natura 2000 habitat types. The Natura 2000 is a network of nature protection areas in the territory of the European Union, designated under the Habitats Directive and Birds Directive. The Habitats Directive divides the EU territory into nine biogeographic regions, each with its own ecological coherence. Natura 2000 sites are selected according to the conditions in each biogeographical region: selected sites represent species and habitat types under similar natural conditions across a suite of countries. These biogeographical regions are somewhat similar to the ecoregions, and the layout is slightly less detailed. Refinement of these large Natura 2000 biogeographic regions is recommended especially in areas where endemic species and habitats are concentrated. Smaller tailor-made units that better express the potential for optimal biodiversity, and in which biodiversity management and management of ecosystem services can operate at the proper scale, are needed (Jansen 2009, 2011). According to Lant et al. (2008) potentially effective remedies against the loss of ecosystem functions lie in the development of ecosystem districts.

The construction of a plant sociological garden is perhaps the closest to popularising habitats, biotopes, vegetation types, plant communities or even life communities, or whatever these clearly recognisable units in the landscape are called. Such gardens can make both urban and non-urban people familiar with the types of vegetation in their wider environment. For example, they will recognise the habitats in their region and may see similarities with other ecoregions where they go on vacation or on business.

Indonesia is home to 15% the total flora of the world, has 40–50% endemism and 47 different ecosystem types (Wikramanayake et al. 2002; Hutabarat and Wilkie 2018). The Indonesian government is establishing regional botanical gardens in each of the 47 ecoregions of Indonesia. This new initiative is potentially very important for in situ and ex situ conservation of the Indonesian flora (Hutabarat and Wilkie 2018).

In Singapore, situated in the ecoregion 'Peninsular Malaysian rain forests' of the Indomalayan realm, it was recognised in a relatively early stage that affinity to nature is an important issue (Malayan Nature Society 1990). A more recent Nature Conservation Masterplan (National Parks Board 2009) comprises four thrusts: (1) conservation of Key Habitats; (2) Habitat Enhancement, Restoration, and Species Recovery; (3) Applied Research in Conservation Biology and Planning; and (4) Community Stewardship and Outreach in Nature (Yeo and Neo 2010). When a city takes the initiative to protect wildlife, one of the first things to do is to make an inventory of all species within its boundaries, and perhaps in a network with other cities within the ecoregion in which the city is situated.

In 1990, Brooklyn Botanic Garden acknowledged the importance of local flora and founded the New York Metropolitan Flora project (Moore et al. 2004). This area lies for the major part in the ecoregion 'Northeast US Coastal forest' of the Nearctic realm. The project's purpose was to document all vascular plants that grow without cultivation in the metropolitan area. The next step is to determine which species are endemic to the ecoregion, which are native, non-native, and which are invasive. A further step is to apply the acquired knowledge to the development of green places in the city.

In Tokyo, largely situated in the ecoregion 'Taiheiyo evergreen forests' of the Palearctic realm, native species are used for planting in parks. The city learned from the experience with a previous project, that when developers are required to provide greenery in urban areas, they for reasons of maintenance and pest control tended to select cultivars and invasive alien species. As a result, some cultivars or invasive species spread their habitats and seriously impacted on the habitats for native species. Now the city promotes an increase in the quality of small green spaces, and making networks of habitats for indigenous wild life settings. These are major goals for a new guideline: greening for biodiversity conservation and networking for indigenous wild life (Bureau of Environment 2014).

In Beijing, largely situated in the ecoregion 'Central China Loess Plateau mixed forests' of the Palearctic realm, scientists conducted butterfly sampling and questionnaire surveys in ten parks (Sing et al. 2019). The questionnaire aimed to explore park users' perceptions of butterfly diversity in urban parks and the relationship with human well-being. The total species count of this study was similar to studies from other megacities in the Sino-Japanese and East Palaearctic zoogeographic region, but the lack of an intrinsic ecological concept in the design of most parks may contribute to the relatively low butterfly species richness in urban parks. It was the first butterfly data collected for Beijing urban landscapes, and it highlights the importance and need for long-term butterfly monitoring.

Seattle, largely situated in the ecoregion 'Puget lowland forests' in the Nearctic realm, was the first U.S. city to adopt a green area ratio, known as the Green Factor. This is a score-based code requirement that increases the amount and improves the quality of landscaping in new development through the provision of green roofs, rain gardens, vegetated walls etc. It aims to manage storm water runoff, aesthetically enhance neighbourhoods, and improve habitat for birds and beneficial insects (City of Seattle 2015). The city promotes the use of native plants (but also non-native) that are adapted to the region (City of Seattle 2019).

In São Paulo, largely situated in the ecoregion 'Serra do Mar coastal forests' in the Neotropical realm, the number municipal parks doubled between 2005 and 2010. In terms of area, the growth was from 15 million to 24 million square meters (Mello-Théry 2011). Vegetation has been used as an index for assessing the quality of life, the characterization of the landscape of streets, squares and parks. The municipal Green Areas policy treats vegetation as an integrating element in the urban landscape. This, incorporates significant surfaces into the Green Areas System of the municipality, expands tree planting in streets, creates tracks connecting squares, parks or green areas, and aims to recover degraded areas of landscape and environmental importance. It is intended also to give people a contemplative recreational contact with nature (Furlan 2004). In cooperation with several universities, current research is conducted in the project 'One Health and Urban Transformation'.

The city of Cape Town is unique in terms of its high biodiversity, which includes a large diversity of endemic and endangered vegetation types and species, which should be conserved (Holmes et al. 2012). The Cape Floristic Region is well known for its outstanding biodiversity and is recognized as a global biodiversity hotspot (Mittermeier et al. 2011). The region has a long history of conservation. The first reserve, an indigenous forest near Plettenberg Bay east of Cape Town, was officially proclaimed in 1811, one of the first in the world (Grove 1987). Cape Town is largely situated in the ecoregion 'Fynbos shrubland' of the Afrotropic realm. One of the conclusions of a literature study on Cape Town's ecology was that scientists laid sound foundations for the next phase of urban ecology: not only interdisciplinary, but also transdisciplinary (Cilliers and Siebert 2012). Another conclusion was that there was a focus on the entire urban green infrastructure (including private and public open spaces as well as man-made habitats), integration of different academic disciplines (and non-academic contributions). The ecology in cities locally and globally had been compared, ecological patterns and the processes (biological, physical and socio-economical) driving them had been studied, as well as the mechanisms behind the processes.

Wellington (New Zealand) belongs to the Australian realm and ecoregion 'New Zealand North Island temperate forests'. Rastandeh et al. (2018) investigated how the most suitable patches of vegetation in urban landscapes can be identified, ranked, and prioritised as potential urban wildlife sanctuaries. One of those potential areas was the Wellington Botanic Garden (ca. 25 ha). This includes protected native forest, also a variety of non-native species in an extensive Rose Garden.

7 Limits of Nature Conservation Measures in Cities

The two most important taxonomic groups which are represented in botanical gardens, aquariums and zoos are vascular plants and vertebrates. Members of most other groups are not included in any institution in the world. Millions of insect species that are living in tropical rainforests are neither identified and described by science nor represented in zoos. For example it is almost impossible to show living animal species of the deep sea in zoos or cultivated lichens in botanical gardens.

And even for vascular plants in botanical gardens and vertebrate species in zoos, the representation is incomplete and highly biased. Globally, some plant families are represented 100%, e.g. cacti and Didieraceae, whereas only 25% of the orchid species, and less than 10% of the Asteraceae are cultivated (Bundesamt für Naturschutz 1999).

Activities in cities to lower the pressure on species and ecosystems can increase nature conservation activities, helping the survival of certain species by reintroduction into the wild, education and information exchange for increasing the awareness of humans, with the accompanying expenditures. Nevertheless, cities and urban habitats can focus on only a small fraction of all living biota and habitat types.

8 Outlook

Even if cities are sparsely vegetated and without untouched nature, and even if cities have few natural elements, they contain the conditions—a concentration of humans, buildings, money and short distances—that are the prerequisite for investments both in species living in urban and species living in non-urban habitats.

The arrangement of natural and semi-natural habitats, green spaces, public parks, greening activities and plantations, botanical gardens, zoos and aquariums in cities: all these can be an important aid for wildlife in the cities and species conservation projects outside the cities. Furthermore, natural evolution can progress even in artificial environments at the interface between natural and cultural processes if certain requirements of the related species and environmental conditions are respected.

At global scales, botanical gardens, aquariums and zoos in collaboration with universities and nature conservation institutions have now developed ambitious programmes and activities in the fields of conservation, research and education.

These are increasingly supported by governments, official authorities and private sponsors via networking, exchange of information, and fund-raising campaigns.

A network of well-equipped and cross-linked botanical gardens, zoos and aquariums could easily enhance their campaigns if they got more money and support by the public.

Schoolchildren and students should come in contact with nature not only during holidays or theoretically in the classroom, but also face to face in the vicinity of their daily life. For more than half of the world population, this immediate vicinity meanwhile is dominated by buildings and streets, humans, traffic and noise.

Nobody is interested in the extinction of a species. Most people have a strong affinity to, and are attracted by, flowering plants, butterflies, birdsongs, and bats in the evening. Thus, activities to enhance the situation for wildlife and rare species in cities might be a win-win situation for both humans and other species living there.

Botanical gardens, zoos and aquariums enable visitors to see rare species that only few people have seen in their natural habitat. Politicians and inhabitants in urban centres have the potential to intensify the relationship between man and biosphere via head, hand and heart. It is a small step to see urban habitats not only as living-room, but also as space for arts or socio-economic problems of humans.

Consider the following possibility which is not unrealistic. A rare bird species, one of the critically endangered species, is living with a small and declining population in the tropics, dramatically threatened with extinction. Captive breeding activities result in an increasing population of the bird due to cooperation and related programmes of zoos. A few individuals of the bird species are released into the wild of a big city in the tropics, where more of the birds can live because the diversity of plant species in gardens offers food for the whole year. Can such a vision become realistic or are there also ethical barriers because the reintroduction to the wild is only allowed to the original habitat—which possibly does not exist anymore?

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Part IV
Synthesis Report

What could be done and what has to be done to realistically reduce the pressure to biodiversity on Earth?

What is the opinion and suggestion of the co-authors of the book to stop the species decline?

In this section co-authors from different scientific disciplines combined their expertise and conviction in a consistent Synthesis Report. It shows that many possibilities and decisions might contribute to the one purpose—no further species loss. We have more than one option.

Land Use Change and the Future of Biodiversity

Carsten Hobohm, Carl Beierkuhnlein, Christine Börtitz, V. Ralph Clark, Nadja El Balti, Andreas Fichtner, Scott Franklin, Thomas Gaens, Werner Härdtle, Andreas Skriver Hansen, Monika Janišová, Jan Jansen, Martin Lindner, Michaela Moro-Richter, Volker Müller-Benedict, Konrad Ott, Karl Christoph Reinmuth, Nils M. van Rooijen, Mattias Sandberg, Joop H. J. Schamineé, Cindy Q. Tang, Hans-Christoph Vahle, and Sula E. Vanderplank

If aliens would visit our planet today, one of their first questions to humans might be:
"What are the most important things that you have?"
We think that most people would answer something like:
"Luck, love, health, food, water, shelter, peace, freedom, participation, work . . ."
And:
"What are your wishes for the future?"
We think that most people would answer something like:
"Best conditions for our children and following generations."
And:
"How can you arrange this in the face of all the damage to the nature?"
We think that the aliens would be embarrassed by the uncertainty in our answer.

(cf. Robert May 2010 in Science 329: 41–42).

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C. Hobohm (ed.), *Perspectives for Biodiversity and Ecosystems*, Environmental Challenges and Solutions, https://doi.org/10.1007/978-3-030-57710-0_19

Abstract This synthesis report is a meta-analysis of perspectives for biodiversity and ecosystems, with a strong focus on human impacts on the environment, and a work order to enable and manage the protection, survival and evolution of all species on Earth. The goal is to protect nature without any further species loss (*Zero Extinction*). With this report, we assess alarming signals from the environment; determine the needs of threatened biota and the required actions to manage and protect landscapes and ecosystems; and identify some inescapable tendencies, challenges but also possibilities. The story of humans on Earth is at a critical juncture.

Human behaviour is inherently dependent on physical and societal relations, including orientation and positioning within the physical environment. There is no single cultural benefit that is independent of provisioning through ecosystem services. Humans are part of the environment, acquire all needs from it and, as such,

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depend on its integrity and management for life and well-being. Moreover, if human impacts to the environment continue to increase the risk of rebound effects impacting human life and health will increase as well.

Whenever a biome, ecosystem, habitat or species is heavily impacted or threatened with irreversible transformation or extinction, prevailing environmental conditions are relevant and should be observed, analysed and remedied as necessary and where possible. Ecology examines the evolutionary, historical and more recent interplay between biological life and the abiotic environment, while the role of social science and the humanities is to question the physical and social landscape, and how and why it should be protected or influenced, e.g. by nature conservation measures under political and economic, ethical and legal considerations. Thus, for all inter-relationships between natural and sociocultural processes, a joint venture in the form of social-ecological thinking is necessary to combine natural sciences and the humanities.

With this contribution, we combine ecological knowledge with social science knowledge (s.l.) through the participation of scientists of many different disciplines.

We analyse history and current processes to assess risks, threats and possibilities, and call for an array of regulations and measures that can contribute to halting of biodiversity loss and that assist in achieving a sustainable future. Regulations comprise creativity, cultural incentives, social norms, environmental education and economic investments—such as payments for sustainable agriculture, forestry, and fishery; investments in water, soil and air purity; and much clearer and stronger legal restrictions and consequences around waste streams and environmental degradation.

Moreover, a gradual change from profit-oriented economies in the short-run to environmentally-sensitive policies that include systematic environmental programmes in the long term might help to decrease pressure on ecosystems and biota. Such economics might also include the real costs of consumerism, including the impacts of particular products on the environment and on human health.

The greatest hurdle for the continued existence of many critically endangered species is the impact of widespread anthropogenic-driven change in the usage of water, air and land, and industry intensification in agriculture, aquaculture, forestry, urbanisation, transportation and mining sectors. However, there is not one simple solution to solve these issues. We conclude that many of the current developments have to be adjusted or gradually altered in a step-wise manner, especially with respect to existing sociocultural behaviours. Therefore, various concepts, decisions and measures should be discussed and implemented at all scales from local to supranational and among researchers, practitioners and politicians.

Keywords Threats to biodiversity · Value systems · No species loss · Endangered species · Endangered ecosystems · Challenges and consequences · Science for future

1 Introduction

The United Nations set 17 *Sustainable Development Goals* in 2015 as a blueprint to achieve a more sustainable future for all people (Agenda 2030). In comparison with Agenda 21, the goals are more specified, but without course-correction in relation to actual global trajectories and realities. Thus, the broad and inconsistent spectrum of 169 partly competing targets mirrors the present political and economic power bases, rather than health and environmental conditions of a prospective future. This Agenda does not fully consider biodiversity conservation and ecosystems to the same degree it considers economic targets and growth. As a result, biodiversity is respected in a purely utilitarian manner.

Recently, various comprehensive reports on water and land use and/or climate change have been published. These include the *IPBES Global Assessment on Biodiversity and Ecosystem Services* (2019) and the *Special Report* of the *IPCC* on *Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* (2019). These publications represent the current knowledge in climatology accompanied by other scientific disciplines that outline the implications of climate change and land use for human wellbeing and biodiversity. *The Global Risks Report* (2019) assesses the potential interplay, impact and likelihood of economic, environmental, geopolitical, societal and technological categories with respect to potential payments of assurance companies.

However, regardless of many comprising reports and agendas the IUCN recommends the development of a more ambitious global *Biodiversity Agenda*.

There is encouraging global consensus on the need for better stewardship of the natural environment, which can be used as a platform for more tangible successes in practical conservation, and to stem biodiversity erosion. We here focus on direct threats to and the survival of biodiversity, and the importance of ecosystem and habitat types for nature conservation programmes and measures. Thus, we elaborate on many current debates in media and science regarding the future of the environment (‘science for future’).

We work on the assumption that anthropogenic threats to natural landscapes and the environment have a greater impact on ecosystems and their species assemblages than natural processes and catastrophes—as all species have evolved to natural environmental conditions including dynamics. Land use change, the intensification of various economic sectors, including fishery, agriculture, aquaculture and forestry, rapid urbanisation, proliferation of chemical substances and their use, have the strongest impact on biodiversity and ecosystems. Invasive and other problematic species, genes, pathogens, climate change, severe weather and other factors are additional stressors.

The analysis of the past is important for the understanding of recent conditions and processes. The identification of current challenges can help to estimate what could be feasible in the future. However, this does not mean that we try to use the picture of the past as a template for the future. The future will be different from the past, and our assessment is not retrospective. We discuss concepts and measures that could mitigate pressure on the environment and promote the survival of species and ecosystems. *Zero Use*, for example, is only one of the various options—yet it is often more of a beautiful idea rather than a realistic proposition. Instead, we endorse an enhanced cultural and creative dimension to conservation planning and management: for example, by organizing sociocultural mechanisms that include education, private or public investments, and legal restrictions.

This report is ordered chronologically, from basic facts and data to ideas, visions and solutions. In the first section (after Material and Methods), we focus on the basics around the theme of the book, i.e. environmental history, environmental consciousness, and on the meaning of communication and education.

The second section is related to current challenges: from the increasing use of resources over general evaluation schemes and normative solutions, to environmental indicators, biodiversity conservation strategies, and the meaning of economies. We acknowledge that humans, plants and animals are competing for resources. We also acknowledge that water use, land use and environmental conditions change along an increasing pressure gradient by a growing human population. The question therefore is: what does this mean for biodiversity and the reliability of environmental processes?

The third section is related to rare, endemic, and/or threatened species, their affinity to habitats, and the prospective management and development of ecosystem types to mitigate the impact of human influences.

The fourth section purports ideas, visions, and possible solutions which at the moment seems far from possible. However, such discussions are often important to find acceptable possibilities.

2 Material and Methods

This synthesis report represents considerations and conclusions of authors who took part in publishing a book on *Perspectives for Biodiversity and Ecosystems*. Like other synthesis reports, this meta-analysis does not show references. However, all relevant sources plus additional information can be found in the relating chapters of the book. This report reflects different analyses and results from various co-authors and disciplines. However, we have tried to combine all of them within the central focus of biodiversity conservation.

Landscape ecology was borne from the idea of understanding human impacts on the environment. We use the term *landscape* in a very broad sense. Landscapes are composed of different structures and habitats, arranged and influenced by both natural and sociocultural processes, and harbour characteristic and often unique species assemblages. Thus, e.g. aquatic, urban, and natural landscapes are included here, and are the most common scale of understanding human impacts.

Habitats are landscape units with characteristic structures and species assemblages. These can be grouped into *habitat types*, i.e. typical formations and communities in their abiotic environment. At the highest level of this classification, *habitat groups* (groups of habitat types) are e.g. urban habitats, forests, freshwater, shallow marine waters, rocks and screes, or grasslands. With a focus on ecosystem functions and energy flows, the same landscape unit (habitat, habitat type, habitat group) can be called an *ecosystem*.

3 Environmental History, Consciousness, Communication and Education

The analysis of the past with respect to human behaviour, environmental consciousness and communication is based on the assumption that we recognise problems for the survival and evolution of global biodiversity. Furthermore, our readiness to perceive and understand changes and risks is a major tool for taking action, and through that, show responsibility for the planet's well-being. Environmental communication and education link nature and culture, making nature not only understandable, but also more approachable and accessible, especially in an increasingly impacted, used and urbanised world.

3.1 Environmental History

Global environmental history shows an increase in the use of natural resources by humans. At the local scale, there are numerous examples of societal and industry collapse due to the overuse of resources, e.g. the fish collapse in the Baltic Sea in the early 1990s. The human population is still growing, accompanied with man-made catastrophes, hunger crises, death and migration, with desperation often the proximal cause of war. Trends in increased resource extraction continue, even though this must ultimately reach an environmental tipping point, despite many local and regional attempts to consider alternatives—such as recycling, frugality and disclaimer, animal welfare, nature protection, and other sociocultural programmes. History to date does not reveal any 'silver bullet' measures to protect the hydrosphere, lithosphere, pedosphere or biosphere at global scales. Thus, environmental programmes have usually been more successful at local and regional, rather than national or supranational, scales.

Migration and dispersal of animals, plants, propagules, and pathogens are both heavily reduced and expanded during the last centuries. At the regional scale, the distributions of local native species are greatly reduced through the erosion of natural dispersal mechanisms (transhumance and herding, water irrigating by flooding, transport of dung) on which plant, insect and other species are strongly dependent. In contrast, there is major artificial trans-continental movement of species at the global scale, resulting in virtually unmanageable suites of invasive species and pathogens, that are not hampered by natural enemies, local competitors or soil pathogens, and create biodiversity-poor novel ecosystems.

Most likely, problems of water quality, quantity, availability, drought, severe floods, tsunamis, damage and reconstruction of ecosystems, and diseases linked to the environment have been and are the strongest environmental challenges for humans, and human impacts are the strongest problem for the existence, survival and evolution of biodiversity and ecosystems. However, because of a narrow relationship between nature and culture a further loss of biodiversity might directly be linked to a loss of cultural conditions and processes as well, i.e. the gradual loss of knowledge, traditions, practices and aesthetics related to nature from cultures all over the world.

3.2 Environmental Consciousness

Which historical landscape and environmental events and processes are important for understanding the present? Survival into and organization for the future depends strongly on perception and memory, on narratives, educated traditional and scientific knowledge, and on the explanation of disasters and behaviour in disaster situations. In general, this perception—environmental consciousness—is influenced by education, i.e. learning and communication, as well as by deeper human practices and traditions, such as religious rituals and spirituality, and other forms of awareness.

In modern cultures, perception and interpretation of the environment changed greatly during the transition from a religious-dominated worldview to a secular worldview. Furthermore, during a very short time, communication channels changed from the development of print media to the global use of modern digital technologies. The amount of available information—including scientific knowledge—simply has exploded across the globe during these last decades.

Handling and filtering of information, in combination with a stronger focus on ecosystems and biodiversity, will be key for the success of biodiversity conservation management in the future. Big data, as an example, may also play a role in modern conservation strategies. The analyses of datasets containing long-term and large-scale species distribution patterns—and combining such datasets with other geographical, sociocultural and environmental data—may improve our understanding of the scale change and guide us in developing scenarios for ecological restoration.

Our collective environmental consciousness is shaped by catastrophes rather than continuity, by sudden events rather than uniformitarian change and by obvious rather than creeping processes, even if the final effects may be similar.

Behaviour can be reactive and proactive: normally it is both. Our environmental consciousness is the result of the interplay between evolution, communication about environmental history, and social behaviour; it cannot guarantee avoidance of further environmental disasters. This may be related to risk-taking in humans: the benefits and risks from a particular environment have to be considered together—for example, coastal regions proffer the opportunity for fish stocks but also present hazards to human life and property.

Do we fear the right things? Communications about danger signals from the environment and risk assessment were useful historically and are still useful, even if only a small proportion of disaster forecasts become reality. Additionally, we are able to forecast dramatic events from very small danger signals by using a combination of fantasy and logic. As a consequence, humans are sometimes overcautious and sometimes heedless. Thus, behaviour has always been adjusted in relation to our knowledge and readiness to evaluate the probability of a risk. Therefore, the answer is clearly Yes: in many cases we fear the right things. And, again, Yes: nothing is wrong with the fact that we are sometimes overcautious. And, also, No: sometimes we do not forecast and instead reap the catastrophe.

In general, the focus of the awareness of humans is directed towards survival and the avoidance of pain. Thus, the state of ecosystems, the survival of natural habitats, and maintaining high species diversity on Earth are not the central goals of our environmental consciousness. This is true even if further species decline limits sociocultural perspectives and the well-being of humans. The subtle pressure of a growing human population on ecosystems and biodiversity does not receive the same attention and fear-response as do catastrophic events involving humans.

3.3 Communication and Environmental Education

Communication about nature and the environment has always been important throughout the history of humankind. We assume that humans learned about their environment by walking around, making observations, engaging in trial and error, and trying to overcome unfavourable conditions by practical solutions or migration. Knowledge was passed from generation to generation through experience, practice and narratives, often in the form of myths or legends, which helped explain the relation of people to their environment and environmental disasters. However, this assumption is justified by theories and plausibility rather than hard empirical facts, since we do not know much about learning and education before humans created documents and other media to communicate complex matters.

The exchange of information developed from *oral* to *written*, from *local* to *global*, and during the last century to *digital*. It is arguable that much of the traditional ecological knowledge handed down orally in the past has been lost—indigenous peoples were tied more strongly to their environment and the need to maintain that environment for their own well-being, while urbanization has led to the opposite. Thus, scientific communication considered the lack of knowledge to be the barrier for implementing policy, but such a deficit-model communication has proven ineffective. Indeed, with the digital age, the amount of information has simply exploded and overwhelmed public debates around conservation.

The development of environmental education represents a chronological sequence over a long time-period and can be divided in different phases:

1. Communication of disaster stories and religious narratives.
   (at local scales)
2. Education in religious institutions and schools regarding water and food production, nature, medicine, astronomy, religion, and other disciplines, with the idea to enable human life and solve social problems.
   (at regional scales)
3. Scientific education of modern concepts to solve environmental problems, including ecosystem services and biodiversity conservation.
   (at regional to supra-national scales)
4. Trans-disciplinary exchange of scientific information and education of children, students, the public and stakeholders in economy and politics, with the purpose to limit environmental disasters and species extinction.
   (at regional to supra-national scales)
5. Environmental education which enables avoidance of environmental catastrophes, species extinction and social disasters.
   (at all spatial scales)

These phases can be seen as a chronologically logical sequence. However, the development in the past was not so clearly arranged, as different aspects occurred at different times and in different regions independently, or overlapped at the same time. Today, a combination of phases 1–3 are still globally relevant; phase 4 only partially exists and can be increased. The last phase has not yet been achieved but is the idealist goal for humanity and nature.

This sequence of educational evolution, combined with the digital media revolution, is accompanied by the growing concern of a disinformation agenda that would have a detrimental impact on positive conservation measures. However, diverse educational programmes show an increasing effort to inform about ecological conditions and to avoid environmental catastrophes; this is based on scientific knowledge from all disciplines that are related to human well-being, health, survival, animal welfare, and the survival of species and ecosystems.

The formal establishment of environmental education programmes started in the twentieth century due to a worldwide growing concern about environmental problems; a good example is the early national park movements around the world. The concepts of *Environmental Education* (EE) and *Education for Sustainable Development* (ESD) meanwhile were established in educational systems across the world. Such programmes are often intermingled between short-term perspectives (health, well-being, profit) and long-term perspectives (survival of ecosystems and biodiversity, resource use, recycling), and between constancy and development. Furthermore, different aspects of economic processes, societal relations, and ecological conditions are merged, with the effect that the goal or combination of targets sometimes becomes rather ambiguous.

The central purpose of *Biodiversity Conservation Education* (BCE) is the analysis and intermediation of the relationship between nature and culture, evolution and extinction, species and ecosystems, natural constraints and human possibilities. In general, the issue of *biodiversity* is more related to natural sciences while questions of *conservation* are part of the ethical-social discourse. Thus, also BCE requires the contribution of various disciplines.

The concept and practice of *Ecological Restoration Education* (ERE) is an example of this as much as it is a novel pedagogical approach for schoolchildren. Schoolchildren are by far the largest educable group of the public. The concept combines insights from the field of *outdoor education* and *ecological restoration* and has the overarching objective of fostering learning about biodiversity through practical experience of ecosystem restoration. The concept includes a strategy to spread interest about the importance of biodiversity and ecosystem management among future generations.

Independent of different opinions about pedagogic concepts and best practices, the enlargement and intensification of environmental education in public and private schools and via media is increasingly assessed as an important measure parallel to political decisions, legislation, jurisdiction, and practical management of ecosystems. Everything regarding resources is based on what society prioritizes, so if society assesses conservation and sustainable use of resources as a high priority, if the public has been educated regarding its importance to our own sociocultural life, funding and effort may result in creativity and real sustainability.

4 Current Challenges

We use expressions such as *effective measure* and *successful programme*. Such terms presuppose a normative-evaluative framework. Social science and humanities approaches can make helpful contributions to the clarification and handling of normative-evaluative questions. For the question of how biodiversity could be better protected in the future, social science and humanities may combine different assessments to a consistent perspective.

When we consider what should be protected, and which changes and measures are needed, we have to value natural, semi-natural and artificial entities. We emphasize that the resource use and human impact on biodiversity is enormous. Accordingly, solutions consist primarily in change of action. Humans can adapt actions through norms, regulations, conventions, and programmes, among other measures. However, such instruments must be suitable, goal-oriented, plausible, convincing, and consistent.

4.1 Resources for Humans, Plants and Animals

All processes of life are controlled by resources such as energy, nutrients, water, and space. The current challenge is to organize and regulate humanity's resource use with respect to ecosystem functions and the indefinite survival of threatened species.

Resource use in the long-term can only be sustainable if the biodiversity and food web of the ecosystems remain complete, i.e. including natural processes and conditions of immigration and emigration. Such natural processes are the precondition for resistance and resilience of the system and minimizes the risk that species become extinct.

Migratory populations and species try to optimize foraging efficiency, minimize predation, avoid pathogens, and be as energy-efficient as possible. All native species, humans and neobiota belong to one or more ecosystems. With respect to resource use, there is no general difference between an invading exotic and a native species: both need space and use resources. Migration of individuals and species, and the adherence of distance among individuals, can be useful for the optimization of the ecosystem's resource use.

Biomass, *productivity* and *species diversity* are important components of every ecosystem. Changes in these components reflect changes in the compartmentalisation and resource use of the ecosystem.

Resources are used by the native species of the ecosystem, as well as by migrating species including humans, and invasive species when they arrive. Humans—like all other species—influence ecosystems in various ways, with differential effects on biomass, productivity and species diversity. In every case, these influences will affect the use and cycling of nutrients and energy within the ecosystem.

Under such dynamic conditions, ecosystems are adapting resource use continuously by adjusting the combination of these components. Productivity is the driver of recent conditions and a precondition for biomass; biomass means storage and is a precondition for productivity; species diversity can increase through immigration and evolution, and decrease from emigration and extinction. In general, ecosystems have smaller productivity, biomass and species diversity during dry or cold periods, than during wet or warm periods.

In highly dynamic environments—such as coastal regions or rivers—high values of biomass cannot be realized. On the other hand, forest ecosystems with a large volume of old trees and biomass will never be extremely productive. Also, the diversity of individuals and species can be interpreted as an adaptation to the use of resources. Ecosystems with high diversity—species and/or individuals—are more productive than ecosystems with poorer diversity under comparable ecological conditions.

Humans influence ecosystem functions in different ways, with different effects on biomass, productivity and species diversity. In most cases, changes to ecosystem functions have consequences for species diversity, which usually decreases, but—dependent on the spatial scale—sometimes increases.

We ask the question "is it possible to estimate the effects of humanity's exploitation of ecosystems?" Furthermore, we promote the hypothesis that it might be difficult, if not impossible, for humans to reduce their overall exploitation, and overall production of energy, goods and waste seriously. In general, species assemblages try to optimize their resource use as compromise between short-term use and long-term survival (*Theory on Assembly Optimization, TAO*). Thus, we can ask 'what could a solution in a worst-case scenario be?'

If one takes an evolutionary or biophysical point of view, there is no reason to assume that humans are something special and outside of the general framework of ecosystems and ecological conditions.

However, in contrast to other species, *Homo sapiens* is a strong engineer of most, if not all, ecosystems. Human need of, hunger for, and use of resources is extreme and increasing. Humans can drastically manipulate the populations of individual species (e.g. whales), with seemingly small effects on overall marine ecosystem stability. But, humans can also alter ecosystem structures and functions by using technologies and chemical substances that impact thousands of species and simultaneously threaten many with extinction.

An open question is if and how a growing human population can find a way to ensure the survival of ecosystems and biota into the future. Recent trends show a growing use of abiotic and biotic resources, including energy, food and materials. We assume that a growing population of humans will continue to increase the overall demand for such resources. However, humans should not extract these all from all ecosystems with increasing intensity. It always has been—and can be increasingly possible—to also produce and harvest resources from artificial and semi-natural systems. Growing cities and urban habitats can be identified as regions with huge potential for resource production and recycling. On the other hand, it is certainly possible to lower the pressure on the environment and natural resources in certain habitat types and nature reserves.

It is clearly both expensive and impractical to produce single-use, non-recycable material for human benefit; these products, whether plastic, fertilizers or medicine, go on to pollute other ecosystems with major hidden costs. Thus, we advocate for the position that resources should be used more strategically, and, following such strategies, that the exploitation of ecosystems and species will be reduced to a minimum in terms of wastage and excess.

Climate change, rampant alien invasive species, and species extinction are but symptoms of increasing resource use and greater globalisation. However, in contrast to climate change and the occurrence of alien invasive species, species extinction is irreversible. Furthermore, declining species richness might have dramatic impacts not only for ecosystems but also for social and cultural processes; this is because species play important functional roles in food webs, cycling of energy and nutrients, and ecosystem services.

4.2 Environmental Value Schemes

On conceptual grounds, environmentalism, sustainability science, protection of biodiversity, restoration ecology, and environmental education all rest on values being attributed to natural entities such as species, ecosystems, landscapes. All assumptions about protective goods rely on value judgements. In general, ethics reflects upon both values and commitments (rules, obligations). Values are about goodness (axiology), while rules are about rightness (deontology). Environmental ethics deals with values and commitments within human-nature relationships from such reflexive ethical perspectives. Environmental ethics seeks to ground and justify such goodness or rightness.

People usually identify environmental problems and challenges, such as the threat to ecosystems and the loss of biodiversity, through complex evaluations. In evaluations, values and rules often blend into each other. Environmental ethics provides standards for such evaluations. In order to solve environmental problems, activities have to be coordinated and guided by general or specific rules, as in legal governance schemes. Such rules can and should also be evaluated according to legitimacy, feasibility, and effectiveness. Therefore, a consistent framework for the evaluation of normative solutions to environmental problems, and ethical approaches to the valuation of natural, semi-natural and artificial entities, are needed.

Rules (laws, standards, regulations etc.) are important means to overcome certain ecological challenges. The use of rules can be justified by showing their quality. In the evaluation of adequate rules, specific hurdles arise which can be identified if the components of the presupposed evaluations are made explicit. The goal is to develop a framework for the evaluation of rules or rule systems and to present the corresponding evaluation components. Such considerations play an important role, as the explicitness of the evaluation components already helps to identify and locate possible points of agreement or disagreement. Furthermore, according to general ethical theories, evaluation criteria can be specified. Different criteria can be designed for the same issue, depending on the moral theory used.

Examples of evaluations of concrete normative solutions illustrate the high cognitive effort of a systematic and transparent moral evaluation. The evaluation of regulatory frameworks also involves considerable effort. It is possible to use a moral theory to design a scale that provides plausible evaluation criteria. However, it is sometimes not clear what further background considerations can be assumed. In order to obtain plausible and balanced evaluation statements, the results of social, natural and legal research might be taken into account when determining the degree of fulfilment of the criteria. Successful assessments of normative solutions to environmental problems are an inter-disciplinary undertaking. The hurdles that arise when answering questions about the criteria, or checking their fulfilment, are enormous. Policy-making is primarily a choice of rules within rules. Thus, we have to look for rules that guide our evaluations, arguments and the use of evidence. The measure should follow the goal. However, quite often in politics the goal is adapted to the measure. When we talk about evidence in the context of policy-making, we need to achieve a better understanding of rules and rule uses—for example, to predict the possible side effects of certain policies. And—because the use of evidence is embedded in the use of evaluation and argumentation—we need to consider the theoretical background. Therefore, we should argue about the criteria we want to use for evaluating policies. However, it is difficult to involve all those concerned in corresponding discourses on the evaluation of rules. Without a clear goal and robust discussion, it is impossible to find out which rules should be changed and which alternative means could or should be used.

Problems and challenges of ecosystem and biodiversity protection are linked to diverse questions of evaluation. Several approaches to the valuation of natural and semi-natural entities in the context of environmental protection issues exist, especially with regard to biodiversity. Different, and sometimes competing value systems, are used based on different presuppositions, but can nevertheless overlap in content and result. Most prominent approaches are “Total Economic Value” and “Ecosystem Service Approach”. Value systems (typological schemes) are important instruments for the evaluative classification of complex issues. They are also part of the scientific idea for operationalizing concepts and often quantify value questions via monetization (“willingness to pay”).

In order to make an informed choice of the value systems to be used for decision-making in dealing with biodiversity and nature, the presuppositions of the respective system have to be clarified. In particular, the discussion about the role of values in argumentation, evaluation and decision making, about different types of values and their relationship to norms, can provide information about the functions and criteria value systems can fulfil. The importance of different value schemes for ecosystem and land use change is currently being discussed. Since evaluations are inescapable for the overall practice of nature conservation, such practice would benefit if there would be a coherent unified value scheme. It can be argued that such a comprehensive and integrated synthesis of existing approaches, like the anthropocentric and preference-based *Total Economic Value* (TEV) and the *Ecosystem Service* (ESS) approach, along with different value systems being conceived in environmental ethics, is within reach if patterns of reasoning in environmental ethics are outlined and correlated to the categories within TEV and ESS.

A systematic theoretical step towards conceptual unity, and the clarification of the respective presuppositions, helps in constructive exchange and can enable concrete political programmes. TEV and ESS primarily reveal the values and achievements of nature that are difficult for political processes to ignore. However, these approaches are not comprehensive theories of conservation; they are schematic tools rather than theories, but they can and should serve as a catalyst for the environmental axiological discourse. TEV and ESS can serve as solid entry points for a nuanced and richly textured ethical discourse on nature’s values; ESS and TEV can enrich and refine the ethical argumentation patterns; TEV and ESS can use opinion polls to determine how groups of people actually benefit from natural capital, and they can translate this into the everyday language of preferences, interests, compromises and opportunity costs. Such language is the “lingua franca” in our commercialized world. TEV and ESS can also point to the many trade-offs in human-nature interactions. Both TEV and ESS have already become useful schematic tools to make the values of nature visible—not just for devoted conservationists, but also to economically-minded stakeholders. TEV and ESS make it difficult to deny, ignore, or downplay the beneficial values of nature to people. Both TEV and ESS point out the interfaces between environmental ethics and environmental economics. The debates at the interfaces are about discounting, compensation, replacement costs, replacement of functions and (“de re”) the uniqueness of some very special natural monuments. The quantification and monetization of the instrumental values not only emphasize the ecological value of nature, but also provide information for market-oriented companies. Practical considerations may speak in favour of choosing economic value systems, as they are operationalised; but this should not come at the price of the suppression of ethical value systems, as moral beliefs are an integral part of our way of life—and preference-based judgements should be in reflective balance with our other moral beliefs. Preference-based approaches are not wrong, but may obscure the profoundness of axiological and moral life. While TEV and ESS identify values people factually hold, environmental ethics reflects upon coherence, appropriateness, rightfulness, and grounding. People who use these TEV and ESS tools may also realize that these can also hide and conceal deeper philosophical problems if they are taken as the ultimate ethical wisdom.

Ethical challenges, such as (1) attribution and grounding of evaluations, (2) the demarcation problem of inherent moral values in nature, (3) problems of distributive environmental justice, (4) the issue of virtuous attitudes towards nature, and (5) spiritual encounters with/through nature are neither resolved by TEV nor by ESS. For example, both TEV and ESS abstract away the crucial topic of overcoming anthropocentrism by attributing inherent moral value to non-human beings. Such challenges are topics of environmental ethics. The idea of a uniform—*synthesized*—valuation scheme does not require a final and perfect solution of such problems, but it provides a framework for discourse. Evaluation schemes can either hide or reveal the underlying ethical problems. Our strategy is to use such schemes to uncover them. Finally, value systems are adequately designed if they enable well-informed and consistent evaluations, grounded in reasons.

4.3 Relationship Between Economic Power, Biodiversity and Threats

The relationship between economic processes and biodiversity includes benefits to humans via resource use, destruction of ecosystems, biodiversity loss resulting from resource use, and the impact and likelihood of certain natural disasters as rebound effects. However, moderate use can also lead to naturally rich patchworks of habitats, structural diversity, and may stabilize high biodiversity of landscapes with natural and semi-natural habitats.

Countries are connected by international trade—legal and illegal—across borders, sometimes over long distances. For example, illegal logging of ebony and rosewood in Madagascar is mainly promoted by the luxury market in Asia. However, a small percentage of timber from Madagascar can also be purchased in other parts of the world. As a consequence, the pristine forests in Madagascar are declining in quantity and quality. Many natural products are trafficked as medicine, prestigious objects, pets, or for other purposes, resulting in the risk of extinction for those organisms. Moreover, timber production, trade of rhino horns, shark fins or Totoaba swim bladders in economically weak countries or tribes, are often the result of trade instruments conducted by rich countries or rich people.

Different theories on the relationship between economic processes and indicators on the one hand, and pressure to the environment on the other, have been robustly discussed during the past decades. Depending on economic and ecological indicators, the relationship has been examined as strong or weak. For example, the theory behind the *Environmental Kuznets Curve* is related to the economic development of countries during the last few centuries. According to the Environmental Kuznets Curve, environmental degradation might be highest at intermediate levels of per capita income. However, the way in which economic processes affect the environment is of central importance when discussing the potential efficacy of conservation strategies.

According to our results, the number of threatened species in a country mirrors three main factors: economic factors (GDP and inequality), natural richness (biodiversity), and human population density. These are key factors for understanding the threats and damage to the environment. In general, more species (absolute numbers, and a higher proportion of species) are threatened by economically powerful countries than by developing countries. A combination of (1) economic richness and income inequality in countries with (2) high natural biodiversity plus (3) a dense human population seems to be the most problematic combination for the natural environment.

We additionally established a scheme for evaluating the economic potential of promoting nature conservation programmes and investing in relatable metrics. According to the costs-by-cause principle, countries which are most responsible for environmental degradation should be responsible for the greatest investment contributions to protecting the environment.

With respect to economic power (GDP and GDP per capita) and pressure on the environment, i.e. the number of critically endangered species, economically powerful countries with low environmental pressure might have the greatest potential to invest in biodiversity conservation programmes and mitigation measures at global scales. These countries could be able to effectively support conservation measures in parts of the world where payments show return on investment and conservation measures are relatively cheap. Thus, economically powerful countries with low biodiversity numbers and low environmental pressure might take responsibility for nature conservation at global scales. In contrast, developing countries with rich biodiversity and many endangered species often struggle to protect their landscapes and biodiversity effectively.

In general, we do not see a positive future for ecosystems and protection of species in the face of a global market guided by a profit line policy and a plethora of competing private economical units. Thus, we recommend the financial sector be enlarged to regulations that include the impact of business on the environment; examples are subsidies for environmentally-friendly behaviour and responsible land stewardship, and via environmental taxes on negative effects. Furthermore, all steps in investment and production chains should be accompanied by ethical considerations.

4.4 *Environmental Indicators, Biodiversity Conservation Strategies, and Regulations*

It can be assumed that humans have always observed their natural surrounding and assessed environmental signals (environmental indicators) for survival and wellbeing. What is the importance of environmental indicators in relation to biodiversity and ecosystem function? How expressive are different indicators? How may an environmental indicator help to find solutions for the use and management of ecosystems and the survival of species? What are current concepts, strategies and measures to protect species diversity and ecosystems? How effective are these with respect to observation, indication, control, legislation, efficacy and investment?

The simplest environmental indicators display single aspects, such as temperature or sea level. Others are more complex and combine different factors, e.g. to describe the overall sustainability of a country, or the so-called *ecological footprint* of a person. Even if the model is complex, the message can be concentrated e.g. in a symbol such as a red, yellow or green traffic light for action. However, in the case of combined indicators, it is impossible to reason back to the contribution of single components.

Some indicators, e.g. the *World Happiness Index*, have slight links to the environment, while focusing mainly on social experiences and human well-being. Others are more directly linked to changes in the environment—such as the *Living Planet Index* or the *Red Lists* of threatened species. The *Red List of European Habitats* and the *IUCN Red List of Threatened Species* focus on the changing quality and quantity of ecosystems and threats to biodiversity.

It is impossible to protect all species on Earth in an equal manner, or to leave the environment as it is now. Based on the assumption that there is a global consensus for protecting all species diversity on Earth, different ideas and opportunities have been discussed, developed and applied.

The *No Species Loss Strategy*, the *Biodiversity Hotspot Strategy* and *Ecological Triage* are examples of concepts integrating more than a single strategy or measure. *Payments for Ecosystem Services* (PES) and *Biodiversity Offset Programmes* (BOPs) are recent schemes linking political measures with payments for the restoration of environmental conditions and biodiversity. With respect to the number of annual publications, and the amount of money invested, these measures seem to be of increasing interest. However, the programmes are often used to enable and to support the development and construction of buildings, infrastructure or industry. Thus, the value of such investments for the environment and biodiversity is currently rather ambiguous, and may often be interpreted as ‘greenwashing’ investments.

National Parks and other types of protected areas, *Zero Human Influence Strategies* and *wilderness, restoration measures, eradication of invasive species, activities against hunting and trade* of rare and threatened species, *captive breeding* and *release into the wilderness* and *de-extinction* initiatives comprise multiple concrete measures and treatments which are currently used, developed, and enhanced to protect biodiversity and ecosystem functions.

There is no human life without regulations. In general, regulations are concepts of management according to rules of legal restrictions and private or public initiatives and investments. For example, European legislation has implemented the largest network of protected areas in the world. However, despite this regulation (*Habitats Directive*), it has not been possible to curb the declining quantity and quality of diverse habitat types, nor to stem the increasing number of threatened species in Europe.

Payments in favour of the environment might be adequate. Direct investments have different advantages compared to legal restrictions. For example, they can be used to directly influence population dynamics, food webs, and the range of certain habitat types. Furthermore, relevant programmes can be established in a relatively short time, when money is available; on the other hand, it is also equally possible to cancel such contracts in a relatively short time. With respect to the failure of various species conservation programmes, the relationship between legal restrictions and direct initiatives/investments should be repeatedly re-evaluated, with the aim of higher efficacy. We here call programmes and measures as effective and successful if they guarantee the survival of the target threatened species or habitat.

With respect to current assessments, it can be assumed that both (1) the amount of public and private money invested in nature conservation, together with (2) the myriad of current conservation activities will increase in the future, i.e. the number of protected areas; restoration programmes; activities in zoos and botanical gardens; captive breeding programmes and the release of rare species back into the wild. However, because of political unpredictability, it is questionable if other tendencies such as an increase in the illegal trade of endangered species and natural products can be limited by stronger regulation and control, or if other measures such as education programmes might be more effective.

5 Risks, Realistic Visions and Outlook

The heuristics that *whatever succeeds for the finite, also succeeds for the infinite* has been called the *Law of Continuity*. The probability of something being successful in the future increases if it was successful in the past, and or it is successful at present. The probability of protecting all species on Earth, however, is low, given the rate at which human pressure on global biodiversity is increasing.

Those specific nature conservation planning and management operations that already exist should be empowered and made more effective. Furthermore, the cooperation of politicians, lawyers, economists, farmers, foresters, ecologists, and pedagogues using technological solutions, capital expenditure, media, fantasy, creativity, trial and error should also be intensified, for long-term considerations of success.

Every environmental problem may be considered in respect to spatial scale. Environmental problems might have a global dimension—such as carbon in the atmosphere; others are related to challenges at regional or local scales—such as risks to most local endemics, especially to hyperendemics (highly restricted species). The first step is to assess the spatial scale of direct and indirect factors affecting food webs and biodiversity. As an approximation: concrete landscapes, ecosystems and habitats can be seen as media and tools, and biodiversity as purpose.

However, there is no doubt that increasing monetary investments, relatively and absolutely, is necessary for the salvation of ecosystems and the long-term survival of species. On the other hand, it might be possible to save money by reducing ineffective nature conservation measures; an example may be to stop funding the control of alien species that do not have any measurable negative effect on native species. Therefore, the solution is not only the amount of investment for nature protection, but the effectiveness of investments with respect to a simple indicator: no further loss of species. As an interim outcome, the list of Critically Endangered species should decrease.

5.1 Threatened Species and Risk of Extinction

The risk of any species extinction depends on its range of distribution and the pressure on its population. The smaller the range and the higher the pressure, i.e. death toll of mature individuals, the higher the risk of extinction.

Because of their limited range of occurrence, the survival of *hyperendemics*—i.e. with a range smaller than 1 km^2, or a world population of no more than 50 individuals—and local endemics should have the highest priority. Many hyperendemics and local endemics are considered palaeo-endemics or relictual, having spatial ranges that are remnants of wider historical distributions; others are considered to be neo-endemics, i.e. newly evolved species from the late Pleistocene or the Holocene.

However, every risk threatening the existence of species, including the introduction of pathogens and e.g. tourism, should be minimized. On the other hand, measures to enlarge extant populations and the stockpiling of genetic material can be systematically planned, organized and intensified, for example with support from seed banks, botanical gardens, aquariums and zoos. The public money invested might simply be connected to the success of relating these programmes to the desired actions.

General needs and consequences for different habitat types, associated endemics, and threatened species can be only broadly defined. Thus, the following consequences can only serve as a basis for discussion and should be assessed in every case, and at local to regional scales.

Globally, agriculture, land use change, forestry, aquaculture and biological resource use are the factors most threatening biodiversity. Many terrestrial ecosystems are directly and indirectly affected by conversion, tillage, plantations, construction of roads and buildings, and intensification of use, including diverse physical, chemical and biological components.

In general, the impact of invasive species is stronger where functional roles have not been occupied by native species during their evolutionary history. For example, bird species on islands became extirpated by introduced animals such as rats, cats, goats, and snakes simply because the native, often ground-breeding birds had no experience with such aggressive predators in their evolutionary history. In all these cases, competition was not the problem, or of minor importance; the occupation of a niche by an alien species, which was not occupied before, was the main reason. Therefore, the situation on islands has to be assessed and evaluated in a different way in comparison to most mainland regions.

In the case of hyperendemics and local endemics, it is possible to distinguish between species living in mainland regions and on islands. In general, invasive and other problematic species, geological events and severe weather are more problematic on islands than in mainland regions.

Pollution including industrial and domestic wastewater, washout of fertilizers, hormones, pesticides and other chemical components has a strong impact on plants and animals living in humid, wet or inundated habitats, and in mainland regions. Dry habitats such as desert or semi-desert, and island habitats are often not affected in the same way.

Climate change and severe weather may augment the existing impacts of land use change, and can affect many habitat types and associated biota in the long-run if trends persist. East Asia, for example, is characterized by high species richness and endemism. However, logging, agricultural conversion, and the dramatic transformation of natural landscapes into urbanized areas are the most direct threats to biodiversity. Similarly, because of the over-harvesting of wild medicinal plants, local extinction of species has become common in East Asia and parts of Africa. These threats have likewise meant lost opportunities for phytomedical research and the mobilisation of new medicines.

In view of the potential effects of global climate change on biodiversity, many narrow endemic species in East Asia and other parts of the world are threatened with extinction, as they are unlikely to be able to adapt to new conditions, or to disperse to new favourable habitats in the anticipated time period of change. In general, the combination of distributional, genetic, biological and ecological information must be utilized to conserve endemic and threatened species.

5.2 Habitat Types, Ecological Requirements and Consequences

One of the best ways to protect biodiversity at global scales is to protect habitats as living spaces with respect to ecosystem functioning, including natural food webs.

Forest, shrubland and freshwater habitats harbour the majority of critically endangered species on Earth. However, the level of endangerment among habitats and associated species differs considerably from region to region. For example, in E

Asia and wet tropical regions of S America and Africa, forest habitats harbour many more endemic and threatened species than open and semi-open landscapes. At the same time, these are regions where forest range decreases.

In contrast, in Europe, W and Central Asia, habitat types of open and semi-open landscapes harbour more endemic and threatened species than forests. Across Europe, the range of non-forest habitats is decreasing.

Also in the case of hyperendemics, forest harbours the largest number of taxa. However, with respect to mainland and island regions, there are obvious differences among habitat affinities. For example, coastal and marine, shrubland and rocky areas of islands harbour absolutely and relatively (percentage) more hyperendemics than mainland regions. The situation in wetland and grassland habitats seems to be the opposite, with more taxa on the mainland.

5.2.1 Marine Ecosystems

For marine habitats, biological resource use (e.g. fisheries) in combination with pollution are the most powerful pressures on the species. In general, the pressure increases from deep and pelagic water bodies to neritic and coastal waters. There is no other general solution for problems related to both threat categories, other than to reduce these anthropogenic impacts and establish zero-use zones and broad buffer zones. Pollution includes the noise that humans increasingly put into the water; acoustic noise has a much stronger physical effect in water than in the atmosphere. Therefore, the communication and behaviour of mammals and fish species is impaired by artificial sounds, especially in coastal and shallow waters.

Zero-use zones can have positive side-effects for ecosystem services, such as eventually replenishing fish populations to boost fisheries outside the protected zones. In general, the amount of fish and total fish extraction must not be reduced with a patchwork of protected and unprotected zones, particularly if regulations focus on the long run.

5.2.2 Coastal and Saline Ecosystems

Coastal and saline habitats such as coral reefs, kelp forests, seagrass beds, saltmarshes, brackish swamps and shrublands, mangroves, beaches, coastal cliffs, dune ecosystems, and inland saline steppe represent unique structures and have special species compositions. Moreover, they also serve as nurseries for fish stocks or as territory for ground-breeding birds.

Dunes, saltmarshes and mangroves serve as barrier systems against damage caused by storms, and support wastewater purification. These habitats are heavily affected by destruction from residential housing development, commercial infrastructure for tourism, and infrastructure that disregards natural coastal dynamics.

Shipping traffic, tourism activities, and fisheries are the main threats in coastal waters. As a consequence, and to decrease this pressure, the natural seashore dynamics of water and coastal substrates should be permitted, wherever possible. In many parts of the world, for example, dunes are fixed for coastal protection purposes, even if it is not necessary. Dune areas often represent positive sedimentation rates, and structures such as sea dikes might increase coastal challenges. Also, many coastal ecosystems are negatively impacted by invasive species; limiting natural seashore dynamics in combination with invasive species often has negative conservation effects.

Zero-fishery and zero-tourism zones for up to 10% of the coastline and coastal waters may be realistic targets, since the number and range of protected areas on the coasts are increasing worldwide. In many cases, special nature conservation programmes and measures have to be implemented, e.g. to protect turtle nesting sites on coastal beaches and to eradicate introduced species on islands. Ecotourism partially has, and may have further, positive effects. This depends on the intensity of scientific monitoring, the nature of political agreements, and the direction of economic investments.

5.2.3 Freshwater Ecosystems, Mires, Bogs, Fens and Swamps

Aquaculture and agriculture influence rivers, groundwater, lakes, and mires over long distances. Furthermore, pollution including industrial and domestic wastewater, washout of fertilizers, hormones, pesticides and other chemical components often has a much stronger impact on plants and animals living in wetlands than in other habitats, as water is not only the living space, but is also the transportation and dispersal medium. Because freshwater habitats are often relatively isolated from each other, the effects of human-assisted range expansions of alien and native invasive species and pathogens can always become very problematic and should be intensively monitored.

In many regions, wetlands are impacted by construction activities, such as dams and barrages, or by technical regulation of the water table. Such constructions can heavily alter or limit natural processes such as upstream dispersal of freshwater organisms.

Freshwater habitats in Europe are less strongly impacted by new constructions than in other parts of the world. This has to do with the fact that most of these constructions are already in place. Additionally, the European Water Framework Directive does not allow a declining quality with respect to chemical and ecological conditions—theoretically. Indeed, the kinds of threats and the number of endangered organisms living in European freshwater ecosystems are as numerous as in other parts of the world.

The focus has to be expanded to include external factors affecting freshwater ecosystems. Nature conservation measures that are purely associated to issues within the water bodies and immediate vicinity will be unsuccessful on the whole.

In some parts of the industrial world, the removal or decomissioning of dams towards original hydrological conditions has already been realized or is under consideration.

Many mires and swamps in the world store carbon in the ground as humus or peat; wet soils in natural and semi-natural habitats, and the soils of arable land, have the potential to accumulate much more carbon from the atmosphere than the whole above-ground biosphere. Thus, these systems are important for reducing carbon in the atmosphere and play an important role in the carbon cycle on Earth. Humans in many regions have used, or still use, peat as a multi-purpose resource, and—in general—bogs and fens are more threatened and damaged than swamps. Most mires and swamps could simply be protected by regulations that guarantee natural hydrological dynamics.

It is an open question if and how the development and succession of mires, bogs, fens and swamps should be regulated or not, if they e.g. should be grazed or mowed or not. This question can only be answered with respect to local or regional history and conditions. However, also hay production might be an adequate measure to protect the specific habitat wherever the succession to shrubland or forest should be limited.

For artificial freshwater habitats, such as canals or pond systems in urban areas, the question arises how these can be upgraded with respect to wildlife or selected rare species. This question can be answered with a focus on water quality, environmental heterogeneity and connectivity, and also on the limits of human influence and pressure of tourism.

5.2.4 Grasslands

Grasslands were once the largest terrestrial biome on Earth. Today it is the second largest biome. Grasslands provide important goods and services for a range of commercial and communal activities centred on rangeland and livestock-related activities, e.g. with the production of animal fodder (hay) and animal products such as meat, milk and leather. Grasslands also provide a suite of other ecosystem services in the form of carbon sequestration, water production, climate regulation, and landscape aesthetics.

Embedded in grasslands are e.g. wet grasslands and fens, which form a vital part of the landscape matrix and harbor a particular suite of species. Examples of natural Grasslands are the Prairies of North America, the Highveld of South Africa, the Madagascan highlands, the Asian steppes, the Cerrado, Pampas and Paramos of South America, parts of the Australian Outback, and European semi-natural meadows and pastures.

Grasslands are rich and under-appreciated in terms of species diversity and endemism. Together with other open-canopy or limited woody vegetation, these habitats are endemic-rich. The open and half-open landscapes of W and SW Asia, N Africa and Europe are more species-rich than forest in these regions.

The main drivers of diversity and endemism in the Grassland Biome are often the same factors that limit the growth of woody plants. Species pool, dispersal, isolation; adaptation to fire; frost; the continuous reduction of above-ground biomass at local scales; and cultural behaviour are important factors maintaining biodiversity. These have resulted in a proliferation of subterranean growth forms and strong seasonality (plants), seasonal plumage (birds), subterranean burrowing (small mammals), and migrations (local and continental) in response to forage conditions (e.g. large mammals), prey (e.g. carnivores tracking herbivores), and temperature (e.g. birds, butterflies).

Grasslands are among the most transformed biomes in the world, being highly suitable for cropland, plantations, mining and urbanization; natural rangeland is also abused through over-grazing and inappropriate fire management regimes, and is increasingly vulnerable to woody encroachment by indigenous species and to alien species invasion. As a result, natural grassland is often intensely fragmented, resulting in a major need for both species-specific and landscape-scale conservation efforts. Many large indigenous animals have been extirpated, with populations a fraction of their historical size and distribution; this has had a major impact on ecosystem functioning, as natural processes that include migrations have been replaced with more sedentary livestock. Moreover, the species diversity is declining due to the use of mineral fertilisers and pesticides, overgrazing, under-grazing, intensification of use and—in the case of semi-natural grassland—cessation of use.

Decisions made for conservation at regional scales are frequently not strong enough to promote sustainable grassland utilisation and protection of habitats and biodiversity, neither at local to regional nor at national to supranational scales.

Grasslands in Europe and parts of W Asia are not only affected by conversion to cropland or forest and intensification but also by abandonment (under-grazing, no mowing). This has to do with the fact that many grassland types in these regions represent semi-natural and traditionally grazed or mowed grasslands.

For many ecosystems, the classic assumption of optimal nature protection is the protection of wilderness and natural processes, and human influence should totally be excluded. However, many examples in grasslands indicate that human influence—under certain conditions and depending on the intensity—can support nature conservation and biodiversity in a sustainable manner. Furthermore, usage means trade, exchange of money and therefore upvaluation of the system compared with a habitat that is not used. *Not used* and without any price is often seen as *unimportant*.

The first and main goal of the Convention of Biological Diversity is the survival of all biota on Earth, and preventing the irreplaceable loss of biodiversity. Therefore, if human activities can support this goal, interactive relationships that accommodate conservation, cultural activities and livelihoods need not be at odds. In essence, grasslands are *living landscapes* that require human influence in some form, e.g. fire management or other forms of biomass reduction, to function optimally. In fact, often the most effective form of conservation is in situ conservation, through responsible land stewardship by landowners—educating and empowering landowners to be effective stewards of grasslands is the most practical means from a fiscal perspective, given limited government funds to purchase and manage large tracks of land for purely conservation reasons. Adding subsidies to tackle major problems such as controlling invasive species, mitigating soil erosion, managing or re-introducing local populations of endangered species, etc. would assist landowners in meeting the bottom line and maintaining their investment in the land.

Extensive and successfully protected areas in grasslands are rare. As a result, governance of natural grasslands requires the integration of both local and regional scales for effective conservation and sustainable use, and is impossible without a mutually beneficial public-private partnership. Although governments might not be able to directly manage large tracts of land, they should consider substantially investing into research and education that will enable a better understanding of these grasslands as social-ecological systems, with the policy approach that will enable best practice stewardship while promoting and encouraging utilization that benefits local livelihoods and economies. Endangered grassland endemics make charismatic flagship species for grassland conservation. Perhaps the best known are the Bison for the Prairies, the Rhea for the Brazilian Cerrado, the Black Wildebeest for the South African Highveld, and the Great Bustard for the Asian steppes. The re-introduction of former wild ungulates and antelope can be very effective ecologically and economically, as has been shown in North America, Europe and southern Africa.

5.2.5 Heaths and Shrublands

The importance of heath, scrub, savanna, hedges, spatial transition zones and succession stages with woody plants of intermediate height for maintaining biodiversity is often underestimated. Compared to other ecosystem types, such as forest or freshwater ecosystems, heaths and shrublands are relatively less emphasised in the ecological research arena.

These habitats cover a small proportion of the terrestrial land compared to forest, grassland, and other biomes, and include e.g. large parts of the highly endemic-rich sclerophyllous Mediterranean-type (winter rainfall) ecosystems, variously named chaparral, fynbos, garrigue, kwongan, mallee, maquis, matorral, macchia, renosterveld, etc. scattered around the world. The shrublands and savannas of the Cerrado, Brazil, and semi-deserts in other regions are diverse as well. These habitats are rich in species, and are particularly rich in local endemics. Smaller forms of heaths and shrublands are embedded in other vegetation types, notably in montane and temperate systems where they form local communities, e.g. *Ericaceae*-dominated vegetation in alpine zones.

In many regions fire is a dominant ecological driver, with complex successional processes that span annual to more than 30-year cycles.

Heaths and shrublands are most vulnerable to degradation through land transformation from agriculture and urbanization, notably in Mediterranean-climate regions and savannas with summer rain, where there are expanding urban centres and associated local species extinctions. These ecosystems are especially vulnerable to impacts from invasive species, notably invasive grasses and woody species: such invasives can be extremely difficult to manage in rugged terrain covered in thick sclerophyllous vegetation. Woody invasive species also alter fire dynamics in a manner that are detrimental to indigenous seed banks as well as to human well-being and infrastructure. Ecological compromise can also occur from inappropriate use as rangelands for grazing, as natural grazing is limited or replaced. Also, the use of improper fire regimes for land use management can cause successional imbalance.

In some places—e.g. South Africa and Australia—demand for the cut-flower trade from heathland's spectacular floral wealth can compromise the sustainability of wild populations of popular species. Because many heathland species are very narrow endemics, even small-scale changes can affect local species compositions and result in numerous species extinctions.

In those areas where the ultimate natural vegetation potential is wooded, e.g. much of Europe, the semi-natural ecosystems are often replaced with tree plantations where such heaths and shrublands have been abandoned.

The question of what these very dynamic ecosystems will look like in the future is difficult to answer. However, the relatively high number of different habitat types, structures, and species highlights the importance of conservation planning and management of these areas.

Restoration of areas where heathland was historically extirpated, and rehabilitation where it has been degraded, are major current topics of research and practitioner experimentation. Areas that were under woody invasives for significant time periods often still have surprisingly resilient seed banks that favour rehabilitation of the original vegetation, although assistance is usually required with supplementary sowings. Given that many plant species have substantial underground storage organs, it suggests that there is great value for carbon sequestration.

The time which is needed to re-establish dwarf shrub or shrub communities is normally shorter than the time needed to grow old forest. This fact can also be seen as a chance, especially if a rare or threatened species can live in both heath/shrubland and forest. Therefore, the establishment of relating structures might be included in the planning and management at landscape scales.

5.2.6 Forests and Woodlands

Ongoing forest biodiversity loss has significant detrimental impacts on a wide range of ecosystem functions and services, making forest biodiversity conservation relevant for society. Yet, dramatic losses of forest area alongside over-exploitation and forest management intensification counteract global agreements on sustainable development and biodiversity goals.

Consequently, a further decline of primeval forests must be immediately stopped to ensure the survival of genetic reservoirs of a huge amount of biome-specific forest species. In this context, it is important to note that losses of evolutionarily distinct species, and species losses from small families, may have particularly strong effects on ecosystem function, because of a significant reduction of functionally important interspecific species interactions.

Besides an increase in strictly protected forest areas (wilderness areas) across forest biomes, a profound shift in forest management practices towards an ecosystem-based perspective that focus on forest integrity with respect to the whole food web rather than economics seems to be a vital way to maintain both ecosystem multi-functionality and biodiversity in production forests. Allowing trees and forests to mature by significantly minimizing silvicultural interventions would benefit many species that depend on habitats associated with late development phases and a long forest continuity.

Forest ecosystems play a crucial role in global biogeochemical cycles and store huge amounts of carbon. Future carbon sequestration and storage, however, critically depend on tree longevity. Thus, forest preservation and restoration rather than afforestation seems to be a promising way for climate change mitigation. Importantly, species-rich, semi-natural and cultural ecosystems should not be sacrificed for tree plantations, to safeguard their rare, endemic and threatened species. Overall, sustaining the functional integrity of forest ecosystems would favour synergies among biodiversity and multiple benefits that forests provide for human well-being.

5.2.7 Deserts and Rocky Ecosystems

Sparsely vegetated areas such as deserts, semi-deserts, rocks or screes are inhabited by many rare, endemic and also endangered species, especially if the landscape heterogeneity in space is high. The importance of these habitats for the existence of organisms is often underestimated.

Furthermore, the increasing range of desert in many cases is the consequence of agriculture, e.g. due to overgrazing in marginal rangelands that are sensitive to desertification, and has less to do with climate change. This has unfortunately been a theme over the past two centuries in dry zones of Asia, the African Sahel, Karoo of southern Africa, Australian Outback and south-western North America, following the onset of major livestock farming with management practices unsuited to the environmental context. Restoration is sometimes possible, at a huge cost, but is often impossible.

Desert animals are severely persecuted in some places, with local cultural activities decimating original wildlife; North Africa and the Middle East are examples of areas with some of the World's most endangered antelope species, as well as having several extinct desert species from human persecution. In contrast, some desert animals have benefited from domestication and relocation to other continents—the camel and sakar falcon are some examples. War in many dry and desert areas is also a profound impact on biodiversity: war-induced poverty and migration, as well as hunting by militia, has decimated wildlife in the African Sahel, southern Angola, the Horn of Africa, and parts of central Asia. Desert plants can be highly sought after in the horticultural trade—for example the succulent wealth of Namaqualand in South Africa is under tremendous pressure from illegal plant collectors for the international market. In some areas, mineral wealth in arid regions competes with conservation needs, such as in the Northern Cape, South Africa, where various mineral riches require open cast mining that impacts rich local arid endemism. In contrast, politically stable, arid countries like Botswana, Namibia and South Africa—which share the Kalahari and Namib Deserts between them—have successfully protected their "big five" wildlife and other biodiversity through extensive trans-boundary game reserves that balance conservation, tourism and benefits to local people.

In contrast to most perceptions of "tropical islands", arid islands often host some of the most intriguing and vulnerable biodiversity on earth. The Galapagos, Cape Verde islands and Socotra are just some examples of arid or semi-arid islands with unique and aridity-adapted endemism.

Erosion has a negative connotation, while *sedimentation* has a positive connotation; however, both are opposite ends of the same geomorphological processes. Many eroding landscapes—such as coastal cliffs—represent habitats with a rich and unique biodiversity. Many endemic vascular plants, but also certain groups of animals, are concentrated on sparsely vegetated, steep slopes.

Fortunately, most arid habitats can be conserved without much human interference, provided the original landscape is not much impacted. Restoration of degraded landscapes—such as areas that have become desertified—are much more difficult and usually require interventions beyond the fiscal means of individual communities or landowners. In such instances, national or even multi-national interventions are necessary, if embedded cultural beliefs and practices as well as immediate-benefits thinking from landowners can be overcome.

5.2.8 Arable Lands

Agriculture can be subdivided into the organisation and use of arable land; cultivation of permanent crops; the use of grassland as pasture or meadow; and others (e.g. production of biofuel).

One of the key factors that will impact biodiversity into the future is how arable land will be used or misused. Much of the world's food security is currently met through highly mechanised, industrial agriculture on large farm estates with high use of chemicals. At the same time, much of the world is fed through subsistence cropping via manual labour, on small agricultural lots that pass down through generations or which are communally owned and allocated through traditional authority structures. In regions that lack arable land, or in which the climate does not support crop activities, pastoralism is the dominant form of agriculture and food security. Battery-farmed livestock is common in developed countries in which space for free-roaming livestock is limited due to demand for products and due to other competing land uses. A much smaller component to the total production is shifting agriculture in wooded habitats that sees rotational or migrating cultivation of small areas by local communities for their own needs. Biofuel production has replaced food production in many regions, increasing food insecurity locally given that valuable arable land (including virgin land) is transformed for no real agricultural value other than feeding the energy sector.

All of these agricultural activities have impacts on biodiversity, both temporally and spatially. Mass conversion of natural landscapes and accompanied mass-loss of biodiversity has occurred through industrial agriculture (e.g. North America, Europe), with accompanying impacts beyond the areas of cultivation from pollution plumes from chemicals (pesticide, fertilisers); likewise, mass conversion of natural landscapes has also taken place over centuries through communal manual effort (e.g. rice terraces in southern Asia), with probably similar impacts on biodiversity as in industrial agriculture but without the pollution plumes. Pastoralism, as identified under Grasslands, can be positive or negative for biodiversity, depending on management and governance systems that work with or against natural rhythms (drought cycles, seasons, annual fire regimes etc.).

Organic farming is an alternative to industrial agriculture, including a more moderate use of resources and less dramatic impacts on the environment. Currently, this kind of agriculture is one of the largest growing economic sectors. However, organic farming normally requires more space to produce the same proportion of agricultural outputs as industrial agriculture. Furthermore, definitions, legislation, and especially certification, is often not clear and therefore often misused by large producers and retailers. As a result, organic farming (crops and livestock) in modern agriculture is still not as cost-efficient as industrial agriculture to make it economically or environmentally attractive, especially if more natural lands are converted and thus biodiversity impacted further.

The problem of shifting cultivation is the increasing influence of growing tribes also in regions which have been untouched or only little used until today.

A comprehensive goal should be to (1) reduce the global range of arable land, and (2) to reduce the amount of problematic effects on biodiversity and ecological conditions inside and outside of agricultural areas. This might realistically only be possible in a world with a declining human population. As this is not the case, quality should take priority over quantity. If ecological knowledge and the idea of species conservation could be increasingly implemented in what has been called *best practice* agriculture, then the living conditions for wildlife can be enhanced.

Wastage of agricultural products (up to 75%) is a major indicator of inefficiency in the agricultural sector and among consumers, often driven by globalisation and current national and international agreements. Improved agreements domestically can encourage a more efficient supply chain, resulting in less demand on arable land. Scaling down productions to serve local markets may increase efficiency in transportation, decrease production demands, decrease waste and decrease environmental impact.

5.2.9 Urban, Artificial and Horticultural Ecosystems

Due to the heterogeneity and diversity of habitat types and abiotic conditions, the urban species diversity of certain groups of organisms may be higher than in comparable, surrounding rural areas of the same size.

Thanks to horticulture, the greening of roofs and walls, and species conservation programmes, cities and urban areas can play an important role for wildlife and the survival of rare species inside and around urban regions.

Spontaneous natural processes in urban areas should be permitted and facilitated as much as possible, so that evolution can progress even in urban environments, at the interface between natural and cultural processes.

Increasingly, authorities of cities understand that our relationship to nature, including urban climate, biodiversity, and land use is important both for human health and to have support from their citizens for policies regarding biodiversity management and protection.

Even if cities are sparsely vegetated and lacking pristine natural spaces, and even if cities are usually poor in terms of natural elements the concentration of humans, buildings, and money can be used as prerequisite for investments in the nature.

Artificial habitats in cities, settlements, infrastructure, and special programmes have a high potential for trial and error nature conservation projects. In areas without any threatened native species, it might be possible to establish populations of plants and animals which are threatened with extinction in their natural habitat. The arrangement of the composition of natural and semi-natural habitats, green spaces, private and public parks, greening activities and plantations, botanic gardens, zoos and aquariums in cities can be an important aid for wildlife in the cities and species conservation projects outside of the cities. Furthermore, natural evolution can progress in artificial environments at the interface between natural and cultural processes, if certain requirements of the relating species and environmental conditions are respected.

However, such projects are limited to certain taxonomical groups such as birds, insects, bats, vascular plant species, and a few others.

At global scales, botanic gardens, seed banks, aquariums and zoos in collaboration with universities and nature conservation institutions have now developed ambitious programmes and activities in the fields of conservation, research and education. These are increasingly supported by governments, official authorities and private sponsors via networking, exchange of information, and fund-raising campaigns. These institutions play a vital role in the survival of rare species and the re-introduction into natural habitats, independent of where the botanic gardens or zoos are located. However, most of the larger institutions are located in cities, and it can be assumed that these in general have more visitors and money than the ones located in rural areas. As such, the exchange of information including education for schoolchildren has a very high value in cities simply because of the proximity for visitors. A network of well-equipped and cross-linked botanical gardens, zoos and aquariums could easily enlarge their campaigns if they get more money and support from the public. Public payments could also be linked with species conservation programmes. Schoolchildren and students should come in contact with nature not only during holidays or education in the classroom, but also face to face in their vicinity of their daily life. Spontaneous natural processes in urban areas should be allowed to increase, to give the opportunity to city dwellers to experience nature around the corner and feel connected to natural processes as humans always experienced them in the past.

5.3 Realistic Visions and Recommendations

Environmental behaviour depends strongly on experience and conceptual understanding of the natural world. Humans are social organisms with natural and cultural attitudes in their behaviour as part of their nature. We assume that the natural part of human behaviour is not absolutely fixed, and the cultural part, including creativity, is not completely free. The relationship between nature and culture may be a dichotomy at both ends of overlapping attitudes. However, the central part is an essentiality. It is precisely here that much effort is required—with respect to our environmental conditions, survival of the species, and cultural perspectives.

Humans depend on environmental conditions and are part of the ecosystem in which they live, or in which they temporarily stay. Humans are unique ecosystem engineers, and not very different from other organisms with respect to these characteristics and their uniqueness. We assume that the development of landscapes and habitats under human influence is flexible. This also means that current economic and political processes and conditions, which are heavily influenced by powerful economic globalisation and a further growth of the world population, will not be the final answer and can be altered.

However, the political and cultural flexibility that can allow for conditions to change in order to assure the survival of a threatened species become redundant the moment the last individual of a certain species dies. Every species extinction at global scales is a further silent but sudden limitation, of nature and culture, including aesthetic perspectives. Creative design landscapes integrating the survival of species and ecosystems would imply monitoring of threats and the guarantee to avoid any species extinction at global scales. Under fortunate conditions, people should be able to implement adequate programmes without unrealistically expensive investments.

Most countries in the world have signed the *Convention on Biological Diversity* (CBD). The aspiration of the CBD—to avoid species extinctions—requires work on new programmes, investments, legislation, monitoring, creativity and political decisions, not only at the national level, but at all other spatial scales as well. Furthermore, an exchange of knowledge including education, responsibility and money must always be adjusted against any species extinction.

The illegal trade of rare species, and natural products of threatened species, is not meant to eliminate species because this would be the end of the trade connection. We assume that a lack of money/jobs and knowledge might be the main driver. Economic consequences together with educational programmes can be seen as key for a reduction in criminal behaviour since the effect of restrictions alone is often rather small.

The multilateral treaty to protect endangered plants and animals (*Washington Convention, CITES*) is characterized by shortcomings and concerns. It is time to replace the negative list of more than 20,000 species in the appendices by a positive list. A positive list would define products and living individuals of species that are neither regionally nor globally threatened and are legal to trade. The list would be much smaller than the appendices of CITES and therefore could be better controlled.

With DNA barcoding and other well-established taxonomic methods, it should be possible to compare the taxonomic identity of every plant, animal or natural product with such a positive list.

Public goods, ecosystem services, climate, and the survival of the species cannot adequately be managed by a liberal market guided by private economies. We assume that a globalized world guided by a free market aspiration will never enable a system with respect to environmental issues at national, international or global scales. We call for political regulation schemes which focus on zero species loss. Thus, the regulation schemes should organize profit-independent payments (subsidies), environmental taxes, and legal restrictions, which can effectively be controlled by executive authorities.

We recommend to respect a few 1, 10, 50 and 100% rules for orientation.

Economic power of countries and social inequality are important predictors for biodiversity loss. We promote the idea that a serious proportion of the investments and economic productivity should be re-invested and directly paid for survival and evolution of ecosystems, their food webs and biodiversity conservation (PEB: Payments for Ecosystems and Biodiversity). To invest at least 1% of the gross domestic product (GDP) should be no problem for most countries in the world. And to invest 1% of the income should be no problem for the richest people in the world. There are already many positive examples. We are convinced that related investments are adequate payments for the future of humans, our sociocultural life, and biodiversity, and might easily be organized.

Various 10% rules related to ecology, ecosystems, food webs, and other environmental aspects have been proposed, e.g. by NGOs. We here advocate for strong nature protection with a focus on selected and critically endangered species and habitats in at least 10% of the area at local, regional, national, and global scales. *Zero use* is not in every case an adequate path to the goal of *No Species Loss* because activities such as monitoring and special nature conservation measures, such as the eradication of invasive species, eco-tourism, and moderate use, can have positive and stabilizing effects on biodiversity and food webs. We are aware that the percentage of nature reserves in many countries already exceeds 10%, and that protection of 10% of the area and habitats alone would not guarantee the survival of all species.

We recommend enlarging the protected marine and terrestrial areas up to 50% by 2050. In this arena, both human residence and biodiversity, natural and cultural activities should likewise have priority. However, threats in these regions, e.g. a further increase of settlements, arable fields, conversion of habitat types, or other species threatening factors, must be stopped. This half of the globe should share significant parts of all ecosystems and species.

Nature, natural food webs, and ecological conditions of biota should be monitored and respected everywhere, not only in nature reserves but also in cities, landscapes dominated by arable fields, places of mining, and thus, on 100% of the surface of the Earth. This on the other hand, does not mean that all species or non-human processes have to be accepted where they occur. Indeed, in many regions management is required to guarantee environment-friendly conditions and the survival of threatened species.

We promote the idea that a goal of no further species loss can someday be achieved, since an overarching agreement on this goal and the knowledge of adequate measures is already there.