Impact of Land Use and Climate Change on Plant Diversity Patterns in Africa

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The basic problem with using extinction as an indicator is that by the time you get the information, it is too late to take any actions.

Robert Scholes, 2005

Preface and acknowledgements

The work for this thesis was carried out at the Nees Institute for Biodiversity of Plants, Rheinische Friedrich-Wilhelms-Universität Bonn, headed by Prof. Dr. Wilhelm Barthlott, and builds on research on continental and global patterns of plant diversity conducted by the BIOMAPS working group. The study is embedded in the framework of the BIOTA West Africa Project, funded by the German Federal Ministry of Education and Research. Furthermore, it was supported by the project "Biodiversität im Wandel" funded by the Akademie der Wissenschaften und Literatur, Mainz.

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CHAPTER 1

General introduction

Biodiversity, the variety of life, is the origin of all crops and domesticated livestock and thereby the basis for agriculture. At the same time, agriculture is the major driver for biodiversity loss (Mooney, 1999; Sala et al., 2000; Parmesan and Yohe, 2003; MEA, 2005; Thuiller, 2007). The destruction of natural habitats through direct human activities and accelerating climate change are acknowledged as important negative impacts on biodiversity, and thus on the ability of ecosystems to provide crucial goods and services (Leemans and Eickhout, 2004; Foley et al., 2005; Metzger et al., 2006; Ives and Carpenter, 2007; Biggs et al., 2008). In particular, unsustainable land use practices have been identified as one of the largest contributors to species extinction. Land use refers to the purpose for which humans exploit the Earth's surface and immediate subsurface (Ramankutty and Foley, 1998; Lambin et al., 2000; Turner et al., 2003). Due to a growing human population and the subsequent growing demand for food and energy, the pressure on land and hence on biodiversity is increasing.

Changes in species numbers have raised serious concerns about the respective consequences for human well-being. The loss of biodiversity corresponds to an irreversible loss of genetic libraries of intrinsic values (Purvis et al., 2000a; van Vuuren et al., 2006; Duffy et al., 2007). The existence of a diverse life on Earth is an essential precondition for ecosystem functionality and human well-being as it comprises the variety of plants, animals and micro-organisms at the genetic, species and ecosystem level (Chapin et al., 2000; Loreau et al., 2001; MEA, 2005; Díaz et al., 2006).

This study analyzes the possible impact of land use and land use change on plant diversity patterns in Africa.

1.1 Biodiversity in Africa

Spatial diversity patterns of vascular plants

African plant diversity is heterogeneous in terms of species richness and endemism patterning. A clear latitudinal increase of species diversity towards the equator is apparent (Figure 1.1). Species richness is strongly correlated to perhumid conditions, historical climate stability, and highly structured vegetation (Barthlott et al., 2007). In contrast, lowest species numbers mostly appear in perarid to arid desert regions (Barthlott et al., 2007). Species richness may also be related to palaeo-climatic fluctuations (Linder, 2001). Another main driver for species diversity is geodiversity, considered as the diversity of abiotic factors, such as the heterogeneity of topography, geology, soils, and climate. Geodiversity is a driving factor for habitat differentiation of communities and may explain the higher biodiversity in abiotically heterogene regions (Barthlott et al., 1999). Remarkable centers of biodiversity richness are: the Cape Floristic Region, the Albertine Rift, the East Coast, the Congo-Zambezi watershed, Upper and Lower Guinea, the Afrotropical mountains and the West African lowlands (Mittermeier et al., 1998; Lovett et al., 2000; Linder, 2001; Küper et al., 2004; Barthlott et al., 2007).

Conservation of biodiversity

The Convention on Biological Diversity (CBD) defines a protected area as “a geographical area which is designated or regulated and managed to achieve specific conservation objectives” (UNEP, 2000). In Africa, around 740 protected areas covering a whole area of about 2 million square kilometers (ca 7% of the total area) are managed as a principle safeguard for Africa’s biodiversity.

Protected areas are seen as key resources for *in situ* conservation of endangered species, as well as for the protection of landscapes and natural ecosystems. The maintenance of biodiversity is an indicator for its success (Chape et al., 2005; Hannah et al., 2002b).

1.2 Land Use in Africa

Current land use

Africa is the second largest and second most populated continent in the world. In 2009 roughly one billion people lived on an area of about 30.2 million square kilometers (CIESIN, 2005). The African land cover consists a variety of vegetation types such as tropical and subtropical forests (21.4%), wetlands, savannas and temperate grasslands (30%), and deserts (43%), containing a variety of natural resources.

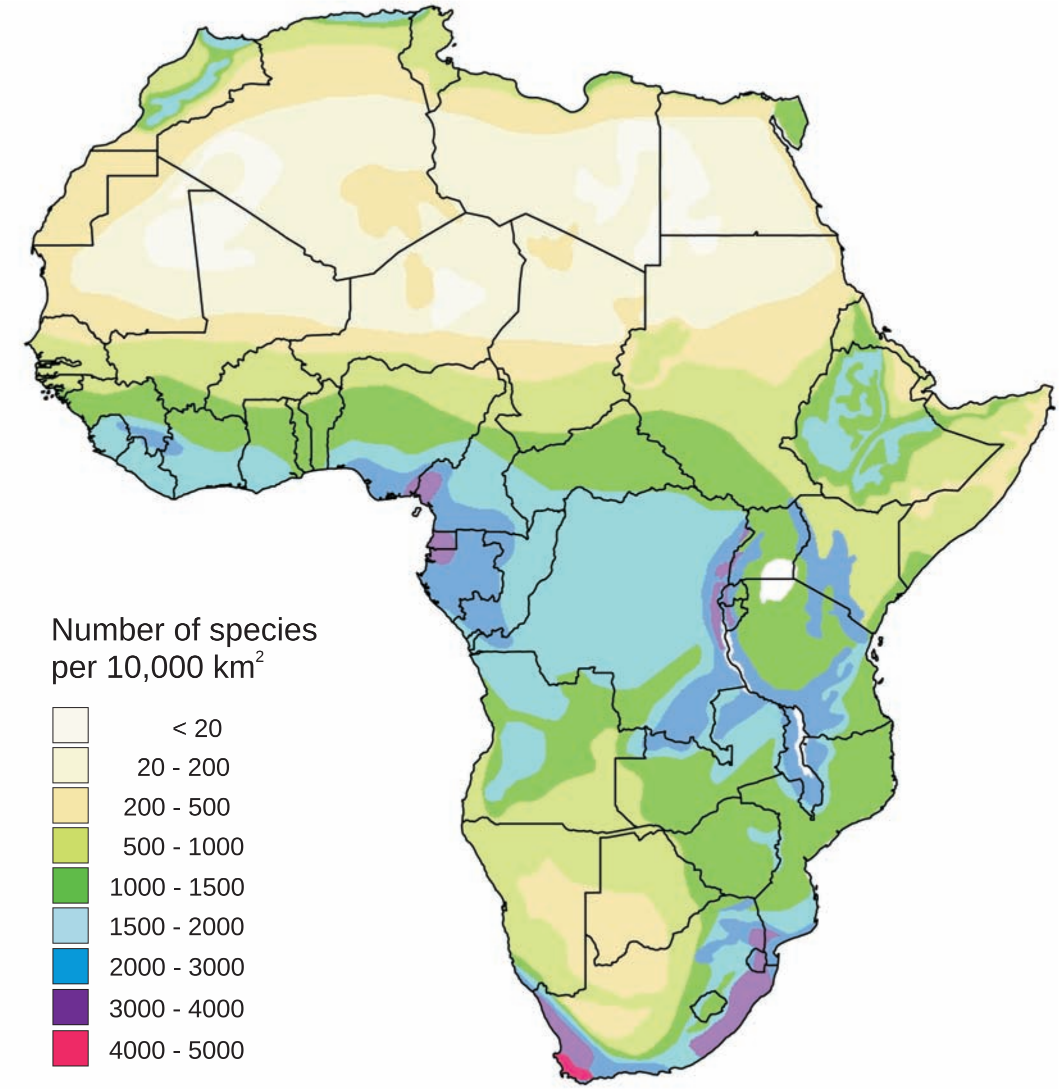


Figure 1.1: Vascular plant diversity patterns of continental Africa (Barthlott et al. (2005)). Species numbers refer to a standard area of 10,000 km^2.

The Congo basin is the second largest contiguous tropical rainforest in the world (Figure 1.2). However, only 20.8% of the land area in Africa is suitable for agricultural use (UNESCO and UNEP, 2002).

The savannas of Africa are commonly used for livestock grazing. Savannas have been in use over 20,000 years and the result is the conversion of a tree-grass mixture to a vegetation dominated by grasses and herbaceous plants, which supplies the demands of pasture (Hoffmann and Jackson, 2000). Corresponding to the gradual change of natural vegetation from savanna to rain forests, livestock farming is less abundant towards the south. Another limiting factor for livestock farming is the appearance of TseTse-flies in humid areas, transmitting nagana and sleeping sickness, which mostly affect cattle and other livestock (Cecchi et al., 2008). The use of arable land for either livestock farming or cultivation of crops largely depends on the environmental preconditions, including water availability and soil quality. Forests are continuously destroyed by the humans for timber and are used for plantations, crop cultivations as well as pasture land. Land is also used for urban expansion and infrastructural development including transportation, tourism and recreation.

Land use change

There is strong evidence that the current trend of human population growth and the increasing demand for food and natural resources will continue in the future. As it is not possible to precisely predict what and where particular changes may happen, different scenarios have been set up that assume possible economic and societal developments for the next century. The example given here adopts the “Markets First” scenario (UNEP, 2007b), which assumes that most of the global societies continue to adopt the values and expectations of market-driven development prevailing in today’s industrialized countries. The scenario assumes a population growth in Africa from about 800 million in 2000 to over 1 billion people in 2009, to more than 1.9 billion in 2050. This leads to a growing demand for food and energy, and with it to a large increase of crop and livestock production areas (Schaldach et al., 2006).

Higher productivity by land use intensification can only partly compensate for this demand, resulting in future strong pressures for additional areas being converted into cropland and rangeland (Schaldach et al., 2006). In general, agriculture will be forced to expand into less suitable areas. For example, these pressures force livestock production to extend northward, into regions with high risk of drought. The urgent need for agricultural land will increase the difficulty of preserving protected areas (FAO, 1998).

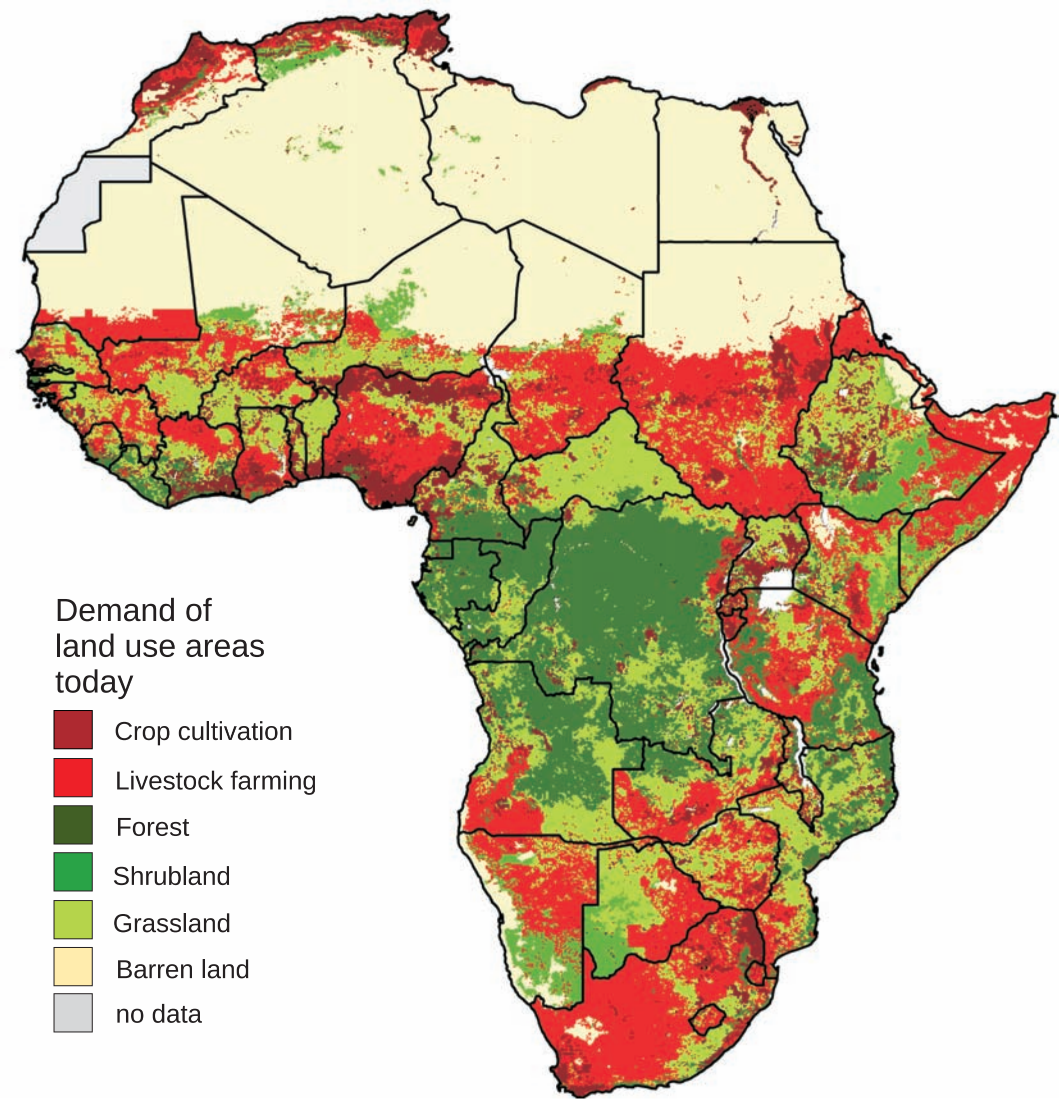


Figure 1.2: Spatial patterns of land use demand for today (2000). Arable land includes the use of land for cultivation of crops and plantations. Livestock farming includes the use of land for pasture and rangeland. Results refer to the dynamic land use model “LandShift” performed at a spatial resolution of 0.1 degrees (Schaldach et al., 2006).

1.3 Biodiversity versus land use patterns in Africa

Current conflicts

There is strong evidence that agriculture changes native habitats of species. Large areas of the African landsurface are already under use. Studies that quantify its impact on biodiversity do not find a consensus on the extent of biodiversity loss (Sala et al., 2000; van Vuuren et al., 2006; de Chazal and Rounsevell, 2009; Alkemade et al., 2009).

Nevertheless, the various types and intensities of land use are identified to differ in impacts on biodiversity: Cultivation of crops, livestock farming and deforestation have a direct impact on biodiversity due to fragmentation and conversion of native habitats. The introduction of amplified technology into land use practices such as the use of machines, fire clearing, drainage and irrigation, leads to an intensification of land use and to larger homogenized cultivated areas such as plantations and extended croplands. Fertilizer and pesticides are utilized to increase crop yields. Besides the desired effects of chemicals, they often have negative and collateral effects and severely alter species composition of adjacent ecosystems (Matson et al., 1997; Foley et al., 2005).

The impact of land use practices on biodiversity also depends on the pristine vegetation: Livestock farming such as goats, cattle and sheep characterizes savannas in Africa. As much as 30% of the centers of plant diversity in the savanna regions are affected by the expansion of agriculturally used land. Livestock feeds on grass, herbs, and leaves from shrubs and trees, or even woody twigs, across large areas. This may lead to plant species composition changes: for example the selective consumptions of grasses and herbs by grazing, strongly biases the natural species competition within a woodland system. Hooves compact soil, and may destruct the protective plant cover, accelerating soil erosion. As a result of grazing animals, many areas, mostly savannas, have undergone a significant and permanent change in species composition and biodiversity (Greenwood and McKenzie, 2001).

Deforestation and the use of arable land for agriculture is the most devastating intrusion into a forest ecosystem. The humid tropical regions of Africa are the most diverse ecosystems on Earth, pristine vegetation consists of dense forests that harbor a large number of different species. Forests are to an increasing extent exploited, cut down for timber, and burnt down to gain land for pasture, cultivation of crops, plantations of commodities, human settlements and infrastructure developments. In the northern savanna regions of West Africa the cutting down of trees is a common practice as source for firewood and building material. The destruction of habitats leads directly to biodiversity loss. Especially in the West African forests approximately 50% of natural areas have already been converted to cultivated land (Poorter and Bongers, 2004).

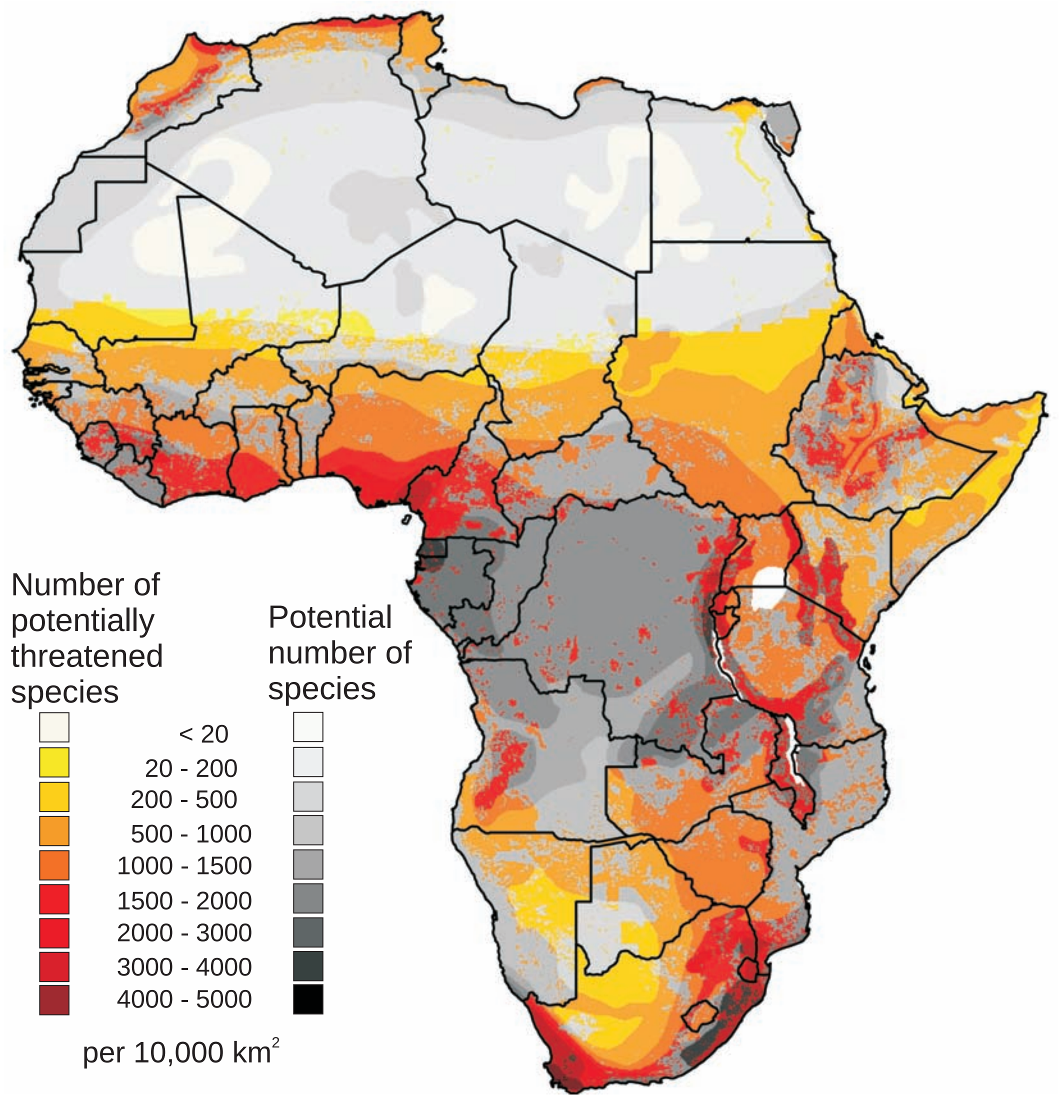


Figure 1.3: Number of species that are potentially threatened by land use in the year 2050 (graduated red colors). Grey areas show potential species numbers without intensive land use activities. Species numbers refer to a standard area of 10,000 km^2. The map shows an overlay of species numbers derived from Barthlott et al. (2005) and future land use patterns derived from (Schaldach et al., 2006).

Future conflicts of land use and biodiversity

During the next 50 years due to a growing human population, a strong pressure on additional areas formerly not in use by man may be converted into cropland and rangeland (Figure 1.3). Based on estimates for the year 2050, this process of expansion may lead to a decrease of native vegetation by 25% (Schaldach et al., 2006). The main trends in land use development according to the *LandShift* scenarios and their conflicts with biodiversity in Africa (see Chapter 5) are:

1) In the West African forests a high pressure of conversion of tropical forest into cropland and in the Guineo-Congolian regional center of endemism (White, 1983) is predicted, threatening especially rich species habitats.
2) In the endemism-rich Sudanian region (White, 1983) a conversion of savanna woodlands into livestock farmland is expected. An increased pressure from grazing in these drought-threatened areas is expected to induce a significant threat on plant diversity.
3) The tropical rain forests of the Congo Basin, as a habitat for a rich diversity of flora and fauna, will lose area due to commercial logging.
4) South Africa holds one of the major biodiversity and endemism hotspots of the world (Barthlott et al., 2005). Human land use may increase due to the high human population growth in this region.
5) Due to a moderate predicted growth of the human population, land use change in the sense of intensification is not found at all for some countries on a large scale by the presented model. But there will definitely be an intensification leading to a change of biodiversity on a local scale.

Alarming is the fact that several important protected areas are predicted to undergo land use change caused by a growing demand for food and energy. Such a habitat change would certainly lead to significant species loss (see Chapter 1.2).

1.4 Maintenance of biodiversity

Biodiversity for human food security

Biodiversity ensures the continued supply of food and energy. Through its role in ecosystem functions and services, it builds the basis for agricultural production, the origin of all crops and domesticated livestock, and their variety. Many plant species are used by humans, providing a supply of essential nutrients and offering thousands of additional products.

Agricultural production relies directly on biodiversity providing important ecosystem services such as pollination (two thirds of all crop species are animal pollinated) and biological pest control. These services depend on a wide diversity of different species: more than 100,000 animal species such as bees, bumblebees, butterflies, beetles, birds, flies and bats, are responsible for the pollination of animal pollinated crops. Moreover, many species of beneficial predators contribute to control pests and diseases. More than 90% of potential crop-insect-pests are controlled by natural enemies living in areas adjacent to croplands (FAO, 2008).

An intact ecosystem also indirectly contributes to agricultural systems as it supports soil fertility, nutrient supply, water cycle and quality. Apart from this it prevents environmental hazards such as soil erosion, flood and drought.

Human development in history strongly relied on this environmental background. A specialized knowledge has been developed that minimizes the risk of crop failure, animal loss, soil infertility and other threatening factors. Also medicinal knowledge was accumulated. Today, around 60,000 distinct plant species are used for traditional and modern medicine worldwide (FAO, 2008).

Land use change and biodiversity - a responsibility for policy

The maintenance of biodiversity is an indispensable precondition for the functionality of ecosystems and the provision of humans with important ecosystem services. Therefore sustainable human development is closely linked to land use strategies that maintain a maximum of biodiversity.

The Convention of Biological Diversity (CBD) committed “to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth” (UNEP, 2000). At present, there is no measurement of progress towards this objective by standardized, regularly repeated measurements of the status of all important biomes and their biota at global and regional scales (see Chapter 3 and Scholes and Biggs, 2005).

Africa’s economical development is facing substantial challenges due to human population growth, climate change, and land use extensification and intensification. High value conservation targets need to be identified and implemented in order to alleviate conservation conflicts and to constrain the growing threat on biodiversity. This challenge can only be addressed by creating public awareness via appropriate education as well as the development and implementation of political decisions on communal, national and international level.

1.5 Scenarios of future development

Scenarios are plausible descriptions of how the future may unfold (Alcamo et al., 1998). The scientific community applies scenarios in order to estimate and assess possible future states of the environment or to examine the effect of alternative policy options. Pictures of plausible future development trends were drawn in a variety of scenario exercises such as the Millennium Ecosystem Assessment (MEA, 2005) or the Global Environmental Outlook (Rothman et al., 2007, GEO-4). In Figure 1.4 the four scenarios of the Geo–4 report are described.

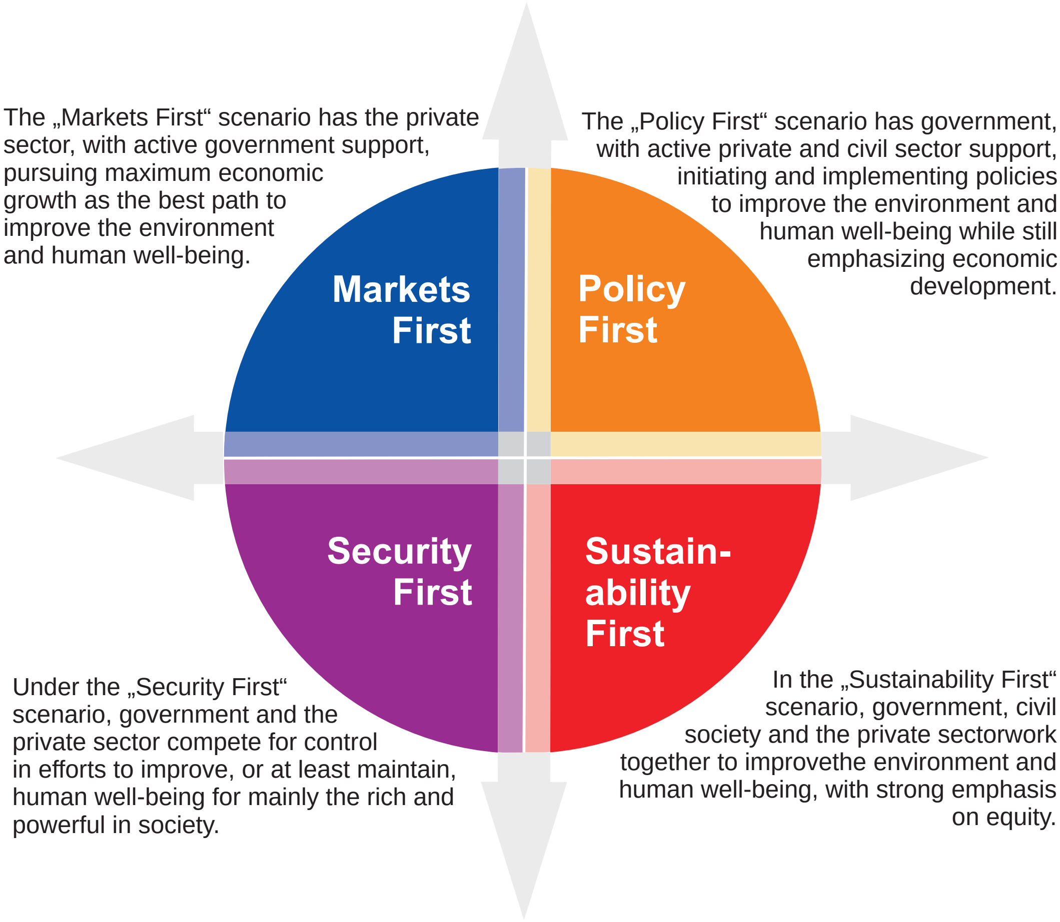


Figure 1.4: The four future development scenarios of GEO-4 (Global Environmental Outlook) after http://maps.grida.no/go/graphic/scenarios1, last visited March 10, 2010. Description refer to (Rothman et al., 2007).

Modelling the demand of future land use areas

The complexity of land-use systems calls for multidisciplinary analyses. Initial efforts aiming at modelling land-use change have focused primarily on biophysical attributes (e.g. altitude, slope or soil type). However, incorporation of data on a wide range of social, political and economic drivers of change is required. Of course this is hampered by a lack of spatially explicit data and by methodological difficulties in linking social and natural data. Land use change modelling is a highly dynamic field of research with many new developments (Veldkamp and Lambin, 2001).

LandShift (Land Simulation to Harmonize and Integrate Freshwater availability and the Terrestrial environment) is a dynamic, spatially explicit land use model, developed at CESR (Center for environmental system research) at the University of Kassel. Cooperation partners are Dr. Rüdiger Schaldach, Jennifer Koch, and Prof. Dr. Joseph Alcamo (Alcamo et al., 2005; Alcamo and Schaldach, 2006; Schaldach et al., 2006; Schaldach and Koch, 2009). It relies on a "land-use systems" approach (Figure 1.5), which describes the interplay between anthropogenic and environmental system components as drivers for land use change. A technical description of LandShift is given by Schaldach and Koch (2009). Chapter 1.5 describes the scenarios used for LandShift derived from the GEO-4 report (Rothman et al., 2007). Out of this report estimations on the future development of the driving forces of land use and land cover change in Africa were derived. Most of these scenarios indicate a strongly increasing human population in the majority of African countries over the next decades.

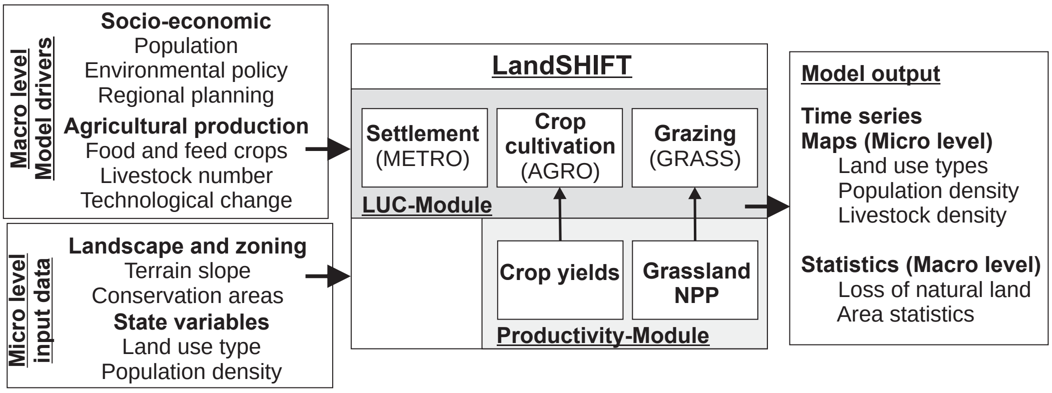


Figure 1.5: Modelling framework of the spatially explicit, dynamic land use model LandShift (Land Simulation to Harmonize and Integrate Freshwater availability and the Terrestrial environment) after (Schaldach et al., 2006).

1.6 The BIOTA Africa project

The BIOTA Africa Project "Biodiversity Monitoring Transect Analysis in Africa" aims at conducting research, supporting sustainable use and conservation of biodiversity in Africa. Initially funded by the German Federal Ministry of Education and Research, the cooperative and interdisciplinary project started in 2000. Meanwhile, several African countries and partner institutions participate, and today more than 350 researchers from 13 countries are involved in BIOTA, subdivided into BIOTA West, East, South, and Maroc. The project contributes to the goals of the relevant UN conventions (CBD and UNCCD), to the Johannesburg Plan of Action of the World Summit on Sustainable Development (WSSD), to the New Partnership for Africa's Development (NEPAD) and is part of the international DIVERSITAS program.

The research at the Nees Institute is embedded in the sub-project BIOTA West, which aims to generate applicable knowledge for the maintenance and sustainable use of biodiversity in West Africa. The identification of the drivers and processes leading to biodiversity loss, the development of methods for the preservation of biodiversity integrating scenarios on the effects of global change, and the creation of tools contributing to the sustainable use of biodiversity are the major developments to achieve these goals. This requires the close cooperation between African and German researchers including a strong component of capacity building on both sides, and the inclusion of the relevant concerned stakeholders and decision makers. BIOTA-West faces this interdisciplinary, integrative and participatory approach in Burkina Faso, Benin and Ivory Coast (www.biota-africa.org).

1.7 Institutional background of this study

This study was carried out in the BIOMAPS working group of the Nees Institute for Biodiversity of Plants, Rheinische Friedrich-Wilhelms-Universität Bonn (www.nees.uni-bonn.de). Our scientific focus is the interdisciplinary macro-ecological analysis of broad-scale patterns of biodiversity (Barthlott et al., 1999, 1996; Mutke et al., 2001; Barthlott et al., 2005; Kier et al., 2005; Barthlott et al., 2007; Kreft, 2007; Kreft et al., 2008). As a part of the BIOTA West research network BIOMAPS analyzes the mechanisms responsible for patterns of species distribution in Africa (Kier and Barthlott, 2001; Küper et al., 2004; Mutke and Barthlott, 2005; Küper et al., 2006; Kier et al., 2009). Effects of global change are involved at continental to global studies (McClean et al., 2005, 2006; Sommer, 2008; Sommer et al., accepted).

CHAPTER 2

Aims of this study

The overarching aim of this study is to analyze the possible impact of land use and climate change on plant diversity patterns in Africa. This thesis is divided into four subsequent sections:

A critical overview of modelling approaches (Chapter 3). There is an urgent need to develop sustainable conservation strategies that requires useful methods to quantify the loss of biodiversity in the context of habitat conversion and degradation. This chapter analyses three different approaches that integrate plant species responses on land use into biodiversity research, and suggests a new comprehensive method.

Integrating niche modelling and remote sensing data (Chapter 4). Integrating species distribution modelling and land cover data emphazises a further potential to monitor habitat loss. In this chapter an integrative approach to monitor species distributions is presented, and the quality of habitat suitability for some representative West African woodland species is identified.

Land use threats to African plant diversity (Chapter 5). Land use is one of the key drivers of species loss. This chapter analyses the conversion of distribution ranges of vascular plant species due to land use activities in continental Africa. Species of particular risk are identified and spatial patterns of most threatened species characterized.

Impact of land use and climate change on African plant diversity (Chapter 6). Climate change is responsible for severe shifts in the distribution of species. We quantify the impact of land use and climate change on plant species in Africa by examining either of these drivers in isolation and then in combination under two different future scenarios.

CHAPTER 3

Impact of land use on biodiversity: A critical overview of modelling approaches

> *You can't stay in your corner of the forest waiting for others to come to you. You have to go to them sometimes.*
>
> Alan Alexander Milne, 1926

Abstract. Interactions between land use and biodiversity are complex and still not comprehensively understood. Studies are compared and critically discussed that incorporate changes in plant diversity into broad scale global-change models, distinguishing between three different approaches: (1) the correlation of species richness with area loss, (2) the development of expert-based indices describing species responses to human activities, and (3) the integration of remote sensing data for monitoring biodiversity. As conclusion, it is recognized that among the examined approaches no reliable and scientific concept exists that is able to comprehensively include all relevant drivers of biodiversity loss. Issues still not properly implemented are the contribution of species interactions, composition, and adaptation, in relation to type, intensity, and extent of land use. For an improved understanding of species responses to land use change, more interdisciplinary collaborations are required in order to develop joint approaches at the interface between broad-scale land use and biodiversity modelling. We propose a synthesis that incorporates aspects of the discussed approaches, although key limitations in data availability and constraints in the implementation process remain.

3.1 Introduction

During the last century, species extinction rates accelerated immensely (Pimm et al., 1995; May et al., 2002; Thomas et al., 2004). Future changes in land use and climate are projected to play an increasingly important role as drivers of biodiversity loss (Hilton-Taylor and Mittermeier, 2000; Hannah et al., 2002a; Skov and Svenning, 2004; Higgins, 2007). Fragmentation, degradation, and conversion are major factors responsible for severe spatial shifts of suitable habitats, accelerating the decline of local species richness and of global biodiversity loss (Sala et al., 2000; van Vuuren et al., 2006; Barthlott et al., 2007; Botkin et al., 2007).

The lack of detailed knowledge of total species numbers and their global or regional distribution makes it difficult to quantify extinction rates precisely (Kinzig and Harte, 2000). The development of adequate indices of biodiversity change due to anthropogenic impacts is an urgent task for biodiversity studies and policies. International commitments require the inventorying and monitoring of biodiversity in order to identify the processes that may impact them.

The UNEP (United Nations Environment Programme) has adopted the Convention on Biological Diversity – CBD – that includes the policy target to significantly reduce the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth (UNEP, 2002). To reach this goal, methods of measuring the status of biodiversity are necessary. A set of criteria that a biodiversity indicator should satisfy was developed in the framework of the CBD (UNEP, 2002):

> A biodiversity indicator should be scientifically sound, sensitive to changes at policy-relevant spatial and temporal scales, allow for comparison with a baseline situation and policy target, be usable in models of future projections, and be amenable to aggregation and disaggregation at ecosystem, national and international levels (Scholes and Biggs, 2005). Moreover, it should be simple applicable and easily understood, broadly accepted and measurable with sufficient accuracy at affordable cost (UNEP, 2002).

At present, no scientific concept exists that develops an indicator to fulfill the proposed criteria. Only a small number of studies relates biodiversity both qualitatively and quantitatively to land use change on a continental or global scale (see for example Sala et al., 2000; van Vuuren et al., 2006; de Chazal and Rounsevell, 2009; Alkemade et al., 2009). This stands in contrast to the large number of studies considering the effects of climate change on species distributions under a range of different scenarios (see for example Walther et al., 2002; Midgley et al., 2002, 2003; Harte et al., 2004; Malcolm et al., 2006; Botkin et al., 2007, and for reviews) (McCarthy et al., 2001; Hitz and Smith, 2004; Schlamadinger et al., 2007). In fact, interactions between climate and land use change may have a greater overall impact on biodiversity change than either of these drivers alone, which was shown in several studies (Hannah et al., 2002a; Rouget et al., 2003a,b; Thomas et al., 2004; Araujo et al., 2004; Skov and Svenning, 2004; Bomhard et al., 2005; Higgins, 2007). However, only a few studies have been undertaken to integrate both drivers (see for example Sala et al., 2000; Jetz et al., 2007; Thuiller et al., 2008; van Vuuren et al., 2006; Alkemade et al., 2009).

Nevertheless, there is strong empirical evidence from studies on the local scale that changes in land use and climate conditions may have severe impacts on species diversity (see for example Kerr and Currie, 2007; Perfecto et al., 2009). In some studies, processes at a lower hierarchical level (typically individual-based approaches) were used to determine dynamics at much higher levels (typically population- or community-based approaches) (Jeltsch et al., 2008). These studies are essential in providing an understanding of how global environmental changes might proceed at a local scale. But a comprehensive biodiversity index essentially requires the complete knowledge of either the biological system of interest or at least a representative sample of individuals of an indicator species (Loh et al., 2005), or should combine a number of factors relating to biodiversity status (see for example Sanderson et al., 2002; MEA, 2005; Scholes and Biggs, 2005; Jetz et al., 2007). This makes many methods scale-dependent and hard to interpret in a comparative context, and much less transferable to the global scale (Magurran, 2003; Scholes and Biggs, 2005).

The key issues of all approaches for global and continental assessments are the complex interactions between biodiversity and land use as well as the limitations of the availability and resolution of species and land use data (Beever et al., 2006; Duro et al., 2007). When assessing the full range of indicators, comprehensive datasets are extremely scarce and not representative due to large gaps in our knowledge (Mace, 2005). These gaps highlight the need for generalization and legitimate the application of broad-scale global-change modelling as an essential prerequisite for monitoring the biodiversity status and for estimating the actual global species loss. Reliable broad-scale results may provide a conceptual baseline to improve conservation planning and management, which is urgently needed (Barnard and Thuiller, 2008).

In this chapter, requirements for useful modelling approaches that identify biodiversity loss are explored in detail. For that purpose, the focus lies on accepted and acknowledged macroecological studies which deal with estimations of species shifts and concentrate on land use as a driver of biodiversity loss on the broad scale. Major strengths and weaknesses of examined approaches will be discussed, framed by the following

questions: Which are the main limitations of the approaches in detecting responses of biodiversity to land use change? How could those limitations be resolved in order to achieve more precise predictions?
As a result of the analyses, we propose a synthesis approach of how species responses to global change might be better incorporated into comprehensive studies. The remaining limitations are highlighted in a discussion, identifying still missing requirements to achieve a much more accurate index describing biodiversity loss.

3.2 Adaptation of the terms biodiversity and land use

Handling of terms. In literature, the terms *biodiversity* and *land use* are often inadequately or not at all defined due to the complex, extensive, and multidisciplinary field of research. In the following section we will find the common denominator used for further discussion.
Biodiversity refers to diversity at the genetic, species or ecosystem level (see Chapter 1.1). In scientific use the term *biodiversity of an area* depicts three primary attributes of an ecosystem: the structure, the function, and the composition (Franklin et al., 1981; Noss, 1990; Soberon et al., 2000; Holt, 2006). Most studies on this subject concentrate on the measurement of species numbers of a defined area (defined as alpha-diversity), and not on the genetic or ecological diversity (Rosenzweig, 1995; Huston and Karr, 1994; Hubbell, 2001). Often, biodiversity definitions consider the relative frequency of each species (Noss, 1990; de Chazal and Rounsevell, 2009). Other indices combine richness with a measure of evenness (the variability of species) or relative abundances (see for example Shannon and Weaver, 1949; Simpson, 1949; Rosenzweig, 1995; Hubbell, 2001). However, in this indices information on species identity and sample size is not visible.
The handling of the terms *land use* and *land cover* have reached a consensus in the literature. Land is a dynamic system on which human and natural systems interact (Parker et al., 2003). *Land cover* refers to the attributes of the biophysical state of the earth's surface and immediate subsurface, including biota, soil, topography, surface and ground water, and anthropogenic structures (Lambin et al., 2000; de Chazal and Rounsevell, 2009). *Land use* describes the modification of an existing natural environment or wilderness by human activities. Most commonly considered is the conversion of native forest, shrubland, and grassland to agricultural and urban land (Lambin et al., 2000). These conversions have been the most important changes in land use in the recent past and are likely to continue in future.

Species responses to land use. The responses of species to land use activities vary considerably, depending on several factors that affect the behavior of species within an ecosystem (Figure 3.1). Important variables are the type, intensity, and spatial extent of land use, the considered species and their individual responses, interactions between species, relations to other variables such as climate change, and the temporal and spatial scale considered. Land use, as the destruction, conversion, and fragmentation of an existing system, represents the key driver leading to a considerable loss of biodiversity (Fahrig, 2003; Duraiappah, 2005). The conversion of natural habitats into land use area may completely degrade the living conditions of particular species, change species composition, and initiate species extinctions. The increasing demand of area for land use often causes the break-up of larger habitats into smaller fractions, which may lose parts of their ecological functions. For example, migration of species, reproduction, and interaction of populations are often disrupted. Altogether, any kind of exploitation of an ecosystem may degrade the quality of a habitat.

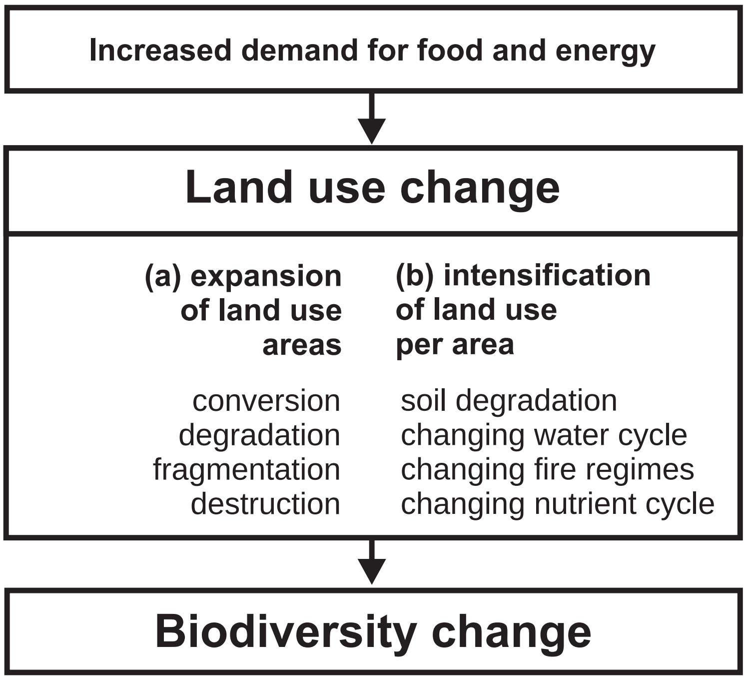
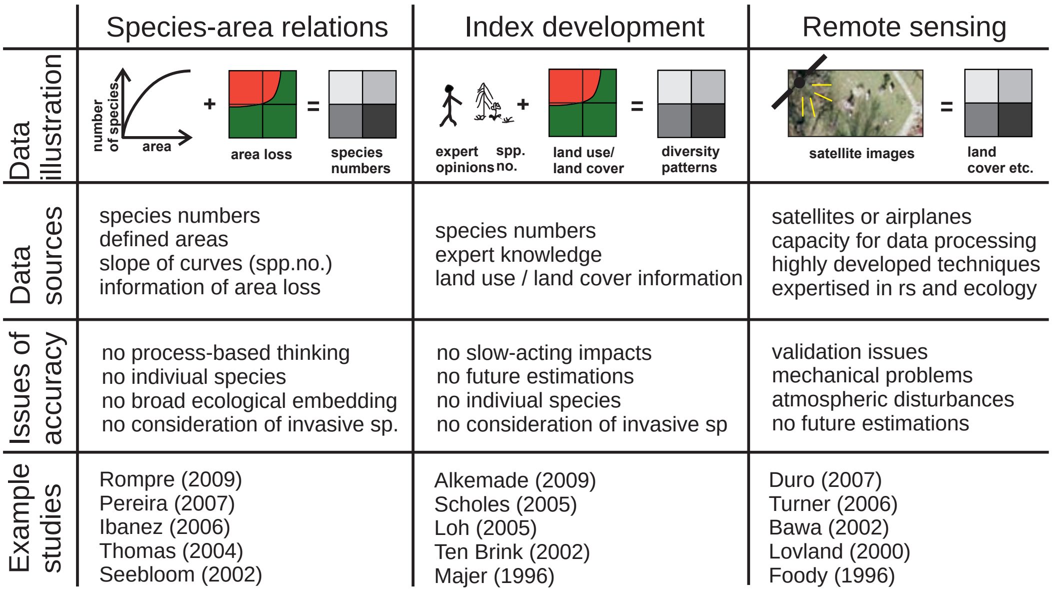


Figure 3.1: Relationship between the demand for food and energy, land use and biodiversity change. The subsequently growing main pressures such as the expansion of used area and the intensification of land use per area result in biodiversity change.

3.3 Three general modelling approaches

The challenge of global change research is to integrate the multifaceted topic of biodiversity and its responses to environmental changes. The main features of accepted and acknowledged studies are initially summarized into three general approaches. Each approach will then be discussed in detail, referring to data sources and method accuracy of example studies. We highlight how key issues could be solved and conclude with a synthesis indicating that the incorporation of all three approaches should be used for a sound and scientific approach to estimate biodiversity loss.



	Species-area relations	Index development	Remote sensing
Data illustration	number of species area + area loss = species numbers	expert opinions spp. no. + land use/ land cover = diversity patterns	satellite images = land cover etc.
Data sources	species numbers defined areas slope of curves (spp.no.) information of area loss	species numbers expert knowledge land use / land cover information	satellites or airplanes capacity for data processing highly developed techniques expertised in rs and ecology
Issues of accuracy	no process-based thinking no indiviual species no broad ecological embedding no consideration of invasive sp.	no slow-acting impacts no future estimations no indiviual species no consideration of invasive sp	validation issues mechanical problems atmospheric disturbances no future estimations
Example studies	Rompre (2009) Pereira (2007) Ibanez (2006) Thomas (2004) Seebloom (2002)	Alkemade (2009) Scholes (2005) Loh (2005) Ten Brink (2002) Majer (1996)	Duro (2007) Turner (2006) Bawa (2002) Lovland (2000) Foody (1996)

Figure 3.2: Schematic illustration of accepted and acknowledged studies that are developed to estimate the responses of species to environmental changes summarized into three general approaches. Pictograms illustrate the rough ideas of the approaches, described by data sources and key issues of accuracy of some exemplary studies.

The species-area relationship approach (*sar – approach*)

The relationship between species numbers and area size have been central to macroecology for several decades (Fisher et al., 1943; Arrhenius, 1921; MacArthur and Wilson, 1967; Rosenzweig, 1995; Kinzig and Harte, 2000). Most estimations of extinction rates generally rely on species-area relationships and have been utilized in the past for the estimation of species loss in response to regional habitat destruction (for example Pimm, 2000; Ferrier et al., 2004; MEA, 2005). This approach is a component of conservation biology and frequently used to formulate recommendations about species preservation and to predict extinction rates (Condit et al., 1996).

Model description. The species-area relationship (sar), also described as power model or Arrhenius equation, is a well-established empirical approach describing the relation between area size and species number. As Rosenzweig (1995) stated, "... you will find more species if you sample a larger area.". The relationship is defined as

$$S = (c * A)^z, \tag{3.1}$$

where S is the number of species, c is the species density, A is the considered, and z is the slope of the relationship (Rosenzweig, 1995; Holt et al., 1999; Lomolino, 2001). In the power model, species richness varies with the value c as well as with the exponent z; both are fitted constants. The exponent z represents the slope and the intercept of the species-area relationship between log S and log A. It describes the rate at which species are encountered in a system, and is independent of the units used to measure area. Although z-values tend to be conservative (typically ranging from 0.10 to 0.50), c-values vary by orders of magnitude (Gould, 1979; Holt et al., 1999; Lomolino, 2001; Kier and Barthlott, 2001).

In the case of land use modelling, the sar – approach is used to estimate the loss of species caused by the conversion of native habitats to agriculture. According to the formula

$$S_{\text{new}}/S_{\text{original}} = (A_{\text{new}}/A_{\text{original}})^z, \tag{3.2}$$

where (S_{new}) is the number of species under the effects of area loss, (S_{original}) is the original number of species, (A_{new}) is the area remaining after land use conversion, and (A_{original}) is the original area. This formula assumes that the proportion of species loss is a result of habitat loss (see for example Kinzig and Harte, 2000; Seabloom et al., 2002; Turner et al., 2003; Ferrier et al., 2004; Thomas et al., 2004; Ibánez et al., 2006; Pereira et al., 2007; Rompré et al., 2009).

In the Millennium Ecosystem Assessment (MEA) a combination of the land use model IMAGE (Image, 2001) and the sar – approach was used to predict biodiversity loss due to a loss of area resulting from expected changes in land use, climate change, and others (MEA, 2005). Following the Millennium Assessment future scenarios, the results suggest that in 2050, as result of land use and climate change 8-12% and 1-4% of all plant species respectively may globally become extinct (in total 20,000-70,000 species). Including the uncertainty in z-value of island, this extinction range may expand to 7-24% (van Vuuren et al., 2006). These analyses were performed at a spatial resolution of 0.5 degrees.

Mittermeier et al. (1998) analyzed the remaining vegetation cover within several selected areas and used a combination of digitized forest cover data provided by the World Conservation Monitoring Center and reference material on past and present trends in the distribution of pristine vegetation. The areas considered areas are threatened by an estimated loss of 75% or more of the pristine vegetation (Mittermeier et al., 1998).

Discussion. The behavior of species richness to increase with area is a robust empirical generalization and is described with the species-area relationship (see for example May, 1975; Rosenzweig, 1995; Holt et al., 1999; Kinzig and Harte, 2000; Desmet and Cowling, 2004). The general use of the enhanced sar – approach that integrates land use change is to quantitatively determine conservation targets. In this regard the *classical* sar – approach is used, based on past and actual biodiversity data to predict species loss due to habitat transformation, which has recently been questioned (see for example Seabloom et al., 2002; Thomas et al., 2004; Ibánez et al., 2006; Pereira et al., 2007; Rompré et al., 2009).

The approach is based on the hypothesized richness of species in a sample of areas. It does not explicitly take into account the complementarity and turnover (beta-diversity) of species, nor any information about where and why species richness declines or even increases. Furthermore, there is no understanding of which particular species may get lost. Thus, more detailed evaluation in order to understand species ecology and to help guiding conservation decisions requires the consideration of point locality data for at least a few species.

The sar – approach does not include any ecological processes such as meta-population dynamics, species interactions, or species responses to land use. For example, species are not restricted to undisturbed habitats but can also live in agricultural landscapes.

Another problematic aspect is the short-term versus the long-term levels of species richness predicted by the model. It does not consider any time dependent responses in its structure. The loss of species richness is a progress (Mace, 2005), and a critical extinction point is still difficult to identify (Lindenmayer et al., 2008).

A further limitation is that the sar – approach can only be applied in one direction. Habitat loss leads to extinction of species, but increase in area does not lead to a similar increase in species, as examined processes are too short compared to the evolutionary timescale. In addition, the sar – approach rests on the assumption that species-abundance within a specified area follows a log-normal distribution (Preston, 1948; May, 1975; Rosenzweig, 1995). It is questionable whether this assumption holds for most areas (it assumes uniform landscapes) and widens the proposed difference between potential and current species distribution patterns (Desmet and Cowling, 2004).

Moreover, the observations of Martin (1981), Willig (2000), and Lomolino and Weiser (2001) indicate the need for careful evaluation of the two constants z and c in the sar – equation. Sampling efforts for calculating richness should be examined before estimating z. Higher values of z are usually accompanied by a corresponding decrease in c values, and vice versa (Rosenzweig, 1995).

The sar – approach may be modified to account for the distribution of species across different habitats by incorporating sensitivity analysis, landscape configuration, and local or regional socio-economic factors to attain accurate predictive power and high conservation relevance (Lee et al., 2006). Further empirical tests are required.

Despite the limitations, if appropriate data and modifications can be implemented, and effects of habitat loss may be reliably quantified, these models may be even applied to much larger areas, . Using detailed habitat loss scenarios, it may even be possible to substantially improve the understanding of how habitat degradation will affect biodiversity worldwide.

Development of expert-based indices

MSA – Mean Species Abundance (Alkemade et al., 2009), BII – Biodiversity Intactness Index (Scholes and Biggs, 2005), LPI – Living Planet Index (Loh et al., 2005), NCI – Natural Capital Index (Ten Brink and Tekelenburg, 2002), and Biodiversity Integrity Index (Majer and Beeston, 1996).

For the description of the impact value of environmental changes on biodiversity, several indices have been developed that build on relations between environmental drivers, land use and species responses estimated by experts. In all concepts, the mean richness of original species relative to their richness in disturbed ecosystems is used as an indicator for biodiversity loss.

Model description. The general concept of the Biodiversity Intactness Index (BII) is very similar to the Natural Capital Index (NCI), the Mean Species Abundance (MSA), and the Biodiversity Integrity Index. Therefore, the details of the BII will be exemplarily introduced, and further it will be focused on the main differences to the other approaches.

The BII is an indicator of the average abundance (the number of individuals per species) of a large and diverse set of organisms in a given geographical area relative to its reference population (Figure 3.3). A reference population is the population that occurred in the landscape before altering by modern industrial society. As these are rarely available, contemporary populations in large protected areas serve as reference. Scholes and Biggs (2005) estimated the impact of a set of land use activities on the population size of ecologically similar species (functional types). Habitat status ranges from “untransformed” in protected areas to “extreme transformation”, such as in urbanized areas. The index is aggregated by weighting the area subject to each activity and the number of species occurring in the particular area. To estimate the reduction in populations caused by a predefined set of land use types, highly experienced experts for each taxonomic group were independently asked. Estimations were made relative to populations in a large protected area in the same ecosystem type in South Africa (divided into six types). Taxonomic groups were divided into functional types such as body size, trophic niche, and reproduction strategy, which respond in similar ways to human activities. Expert-derived estimates were validated against measurements available in literature. All analyses were carried out in South Africa (Scholes and Biggs, 2005).

The NCI and MSA are implemented in analyses done by GLOBIO3 (Alkemade et al., 2009). GLOBIO3 describes biodiversity as the remaining mean species abundance (MSA) of original species (depending on literature summarizing field data on species occurrences), relative to their abundance in pristine or primary vegetation. The MSA represents the average response of the total set of species to any land use activity occurring in the specific ecosystem. Such a response is, e.g., the decline of species numbers in a defined area. Individual species responses are not modelled (Alkemade et al., 2009).

The main difference between the BII and the MSA is that every area is weighted equally in MSA, whereas BII gives more weight to species rich areas. With the BII, ecosystems are weighted by their species richness, and the population sizes (abundances) are estimated for each land use class in each ecosystem. The MSA is also similar to the Living Planet Index (LPI) (Loh et al., 2005) provided by the World Wide Fund For Nature (WWF). The LPI aims to measure the average changing state of populations of vertebrate species from around the world since 1970 (3000 population time series for over 1100 species).

Discussion. The presented expert-based approach is a simply developed index that uses available species data and the expert opinions that describe the responses of species to land use activities. Weaknesses relate to the representativeness of the population data. Data were taken from literature, however not according to a given species range or representative taxa within a biogeographic realm, but just according to availability.

In this discussion we will representatively focus on the BII and the MSA. The indices express the impact of humans on biodiversity very selectively. The background idea is that the vast majority of species are affected mainly through a loss of habitat to cultivation or urban settlements. The disadvantage of the indices is that they are not sensitive to slow acting and diffuse impacts on biodiversity such as long-term effects of habitat fragmentation, climate change, or invasive species. It depends on experts

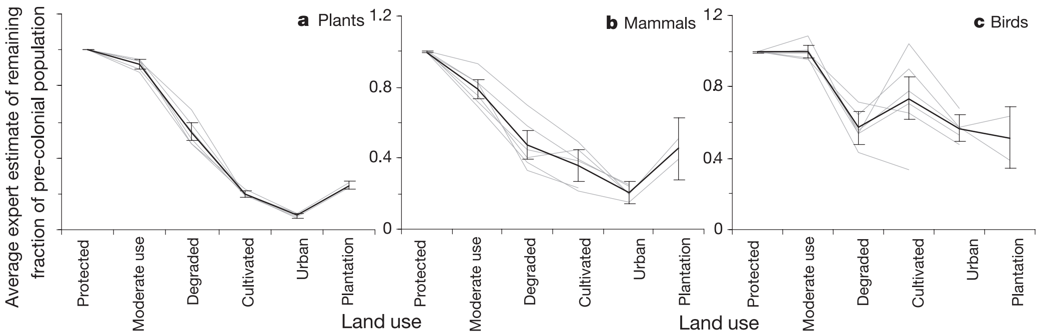


Figure 3.3: Fundamental expert estimations used as input data for the Biodiversity Intactness Index from Scholes and Biggs (2005): the average fraction of original populations remaining under a range of land use activities. The figures (a to c) exemplarily show the estimations for each broad taxonomic group by taxon experts. The gray lines reflect the average estimates for each of six biomes or ecosystem types and the bold line reflects the estimated impact averaged across all biomes. The error bar reflects the 95% confidence interval around the mean estimate (Scholes and Biggs, 2005).

who describe an estimated response of species and the actual status of biodiversity. In addition, it is not possible to create future scenarios of species richness.

The indices are weakly linked to *biodiversity* in its sense of *variation* (Faith et al., 2008), furthermore, they change the meaning of biodiversity as it reflects aspects of species abundance or quantity (the number of individuals per species). Faith et al. (2008) argue that the BII similarly emphasizes quantity over variability, and that a higher BII could as well mean a loss of biodiversity. Such scoring cannot capture all possible gains and losses of actual individual species. For example, the variation of species numbers within the vegetation type cannot be taken into account, if vegetation types are used as reference area. The same total area of a given type might vary in current species numbers. A study provided by Rouget et al. (2006) compels evidence that Scholes and Biggs (2005) may have significantly underestimated the extent of degradation in southern Africa. Almost half of the area assessed by Scholes and Biggs (2005) as *under light use* (and thus *largely intact*) was classified by the fine-scale study of Rouget et al. (2006) as being severely degraded, having lost all its functionality (Lloyd et al., 2002). Therefore, the index may not be suitable for identifying conservation priorities and does not highlight individual species that are under threat. Indicators such as the IUCN Red List of Threatened Species (Hilton-Taylor and Mittermeier, 2000), or indices for biodiversity hotspots (Mittermeier et al., 2005) should be included.

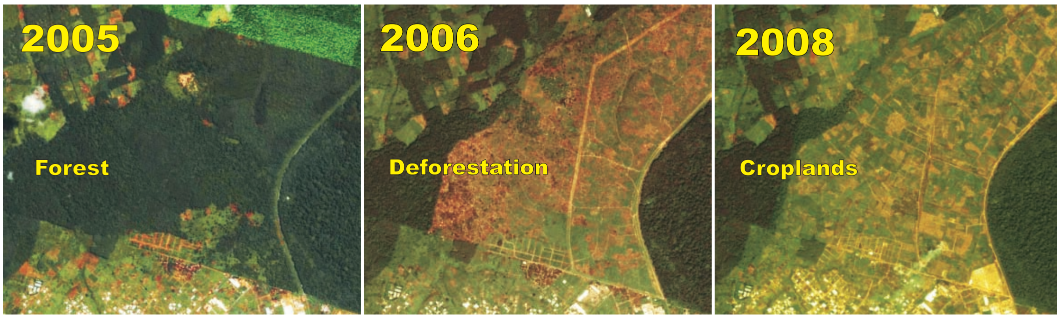


Figure 3.4: Example of satellite time series images near Abidjan, Ivory Coast (5°23’49.69"N/4° 5’7.44"W). Deforestation, urban areas, and upcoming croplands can be observed over a time period from 2005 to 2008 (http://na.unep.net/digital-atlas2/google.php, last visited December 2009).

Remote sensing for biodiversity analysis

Satellite based remote sensing produces imageries that averages information over tens or hundreds of square meters. Advances in spatial and spectral resolutions of sensors allow the remote sensing of particular aspects of the Earth’s surface in a systematic, repeatable, and spatially way. It offers an opportunity for characterizations of some aspects of biodiversity (Achard et al., 2002; Potter et al., 2003; Duro et al., 2007).

Model description. There are two general approaches that integrate remote sensing data and biodiversity analysis: The direct approach is the remote sensing from airborne or satellite sensors to estimate composition or abundance of individual species or assemblages (Turner et al., 2003; Duro et al., 2007). Hyperspectral sensors slice the electromagnetic spectrum into many more discrete spectral bands, enabling the detection of spectral signatures that are characteristic of certain plant species or communities. Measures of leafsurface attributes during different seasons can yield useful information. For example, a leaf area index and the fraction of absorbed, photosynthetically active radiation, combined with edaphic parameters, offer the potential to observe patterns of biodiversity. Height, location and crown dimension can be identified. Another application is the detection and mapping of individual taxa such as invasive species.

Data from Earth observation satellites are routinely used to create land cover maps, and time series data can clearly identify land cover change (Ramankutty and Foley, 1998; Loveland et al., 2000; Bartholomé and Belward, 2005). Many species are restricted to those discrete land cover classes, such as woodland, grassland, or forests. A large number of images are downloadable via Internet; furthermore hyperspatial (very high spatial) resolutions are available from commercial sources. Another advantage for the last years has been the user-friendly application of GoogleEarth^{TM} providing data about land cover over large scales all over the world (Figure 3.4).

In contrast to the direct remote sensing, indirect remote sensing is the observation of environmental parameters as proxies or indicators influencing aspects of biodiversity (Duro et al., 2007). To examine the variety of indirect variables or indicators used to assess biodiversity, categories can be defined that include the indirect measure of the physical environment such as climate and topography, primary productivity, and habitat suitability (with respect to its spatial composition and structure). Remote sensing technologies have been shown to be successful at monitoring disturbances of the land providing indirect measures of changes in biodiversity (Foody, 1996; Duro et al., 2007). Disturbance regimes, occurring over a range of spatial and temporal scales and intensities, such as wind throws, clear-cut harvesting, or large fires, define landscape spatial patterns and thus changes in biodiversity patterns.

Investigators have long considered primary productivity, climate and habit structure (e.g. canopy topography and heights, and vegetation density at different heights) as important in determining species richness and distribution patterns, although there are many more factors important to determine biodiversity (MacArthur, 1972; Rosenzweig, 1995; Gaston, 2000; Nagendra, 2001; Turner et al., 2003). Advances in remote sensing can provide data about some of these environmental parameters. Estimations of primary productivity based on satellite imagery are available at spatial resolutions ranging from 4 m to 8 km, from which several vegetation indices can be derived, such as the normalized difference vegetation index (NDVI) or net primary productivity (NPP). The NDVI reflects the productivity of the ecosystem or the availability of free energy (Currie, 1991). It is an index of green biomass, derived by satellite images with a high spatial resolution. A high correlation has been identified between species richness and the NDVI. For example, Bawa et al. (2002) implemented the potential use of satellite imagery to correlate areas of high and low species richness of trees in tropical forests with high biodiversity loss.

Discussion. The development of technologies such as satellite systems and high developed computers, has given an unprecedented number of remote sensing tools, which are useful and amenable elements for biodiversity research.

Remote sensing methods are robust enough to be used in a variety of applications and spatial scales, while remaining at the same time scientifically rigorous and defensible. Especially terrain logistically difficult to access, requires methods that are able to monitor biodiversity without high costs and field work. Also much larger scales can be observed by less working effort and much faster than by any field work.

On the other hand, the use of remote sensing techniques for biodiversity analysis has some considerable shortfalls. Accurate information is needed to validate remote sensing products, such as ground-truth information from field studies or ground-based sensors.

Misinterpretations of land cover is possible, for instance as human-managed ecosystems (e.g. plantations) or seasonal effects can complicate the classification of the land surface (Bawa et al., 2002). Moreover, atmospheric phenomena, mechanical problems with the sensor, and numerous other effects might produce a high failure value.

Furthermore, the relationship between primary productivity or biomass (NDVI) and species richness is still contentious. Data is lacking linking patterns of primary productivity, large-area estimations of species richness and abundance, and the functional types of organisms that occupy specific habitats and use resources in very different ways (Turner et al., 2003).

A further issue is that land cover maps categorize the land into few classes. Although some species are restricted to discrete land cover classes, the occurrence of many others is not constrained to any of these classifications. This should be considered by relating land cover classes to individual species and species numbers.

Observations of variables that affect levels of biodiversity, such as climate, productivity and topography, can be monitored in a systematic and repeatable fashion. As a great challenge, ecologists and conservation biologists can incorporate remote sensing results into ecological distribution models that are based on correlations of species localities with environmental parameters. This firstly requires a technical expertise to handle remote sensing products, and secondly knowledge about ecological processes in order to combine two separate disciplines. The conjunction of both plays a vital role in the process of converting remote sensing data products into actual knowledge of species distributions and richness.

On the whole, products of remote sensing technologies can help ecologists and conservation biologists in several ways, such as the creation of sufficient networks to monitor biodiversity at large scales. However, those approaches working on a reliable incorporating manner are still not developed to their full potential.

3.4 Results – a synthesis approach

Introduction. The following synthesis incorporates the presented components into an integrative and hierarchical modelling approach (Figure 3.5). It calls for collaborations between disciplines of biodiversity research in order to achieve the best possible results. We suggest three general steps towards a method for estimating current biodiversity patterns.

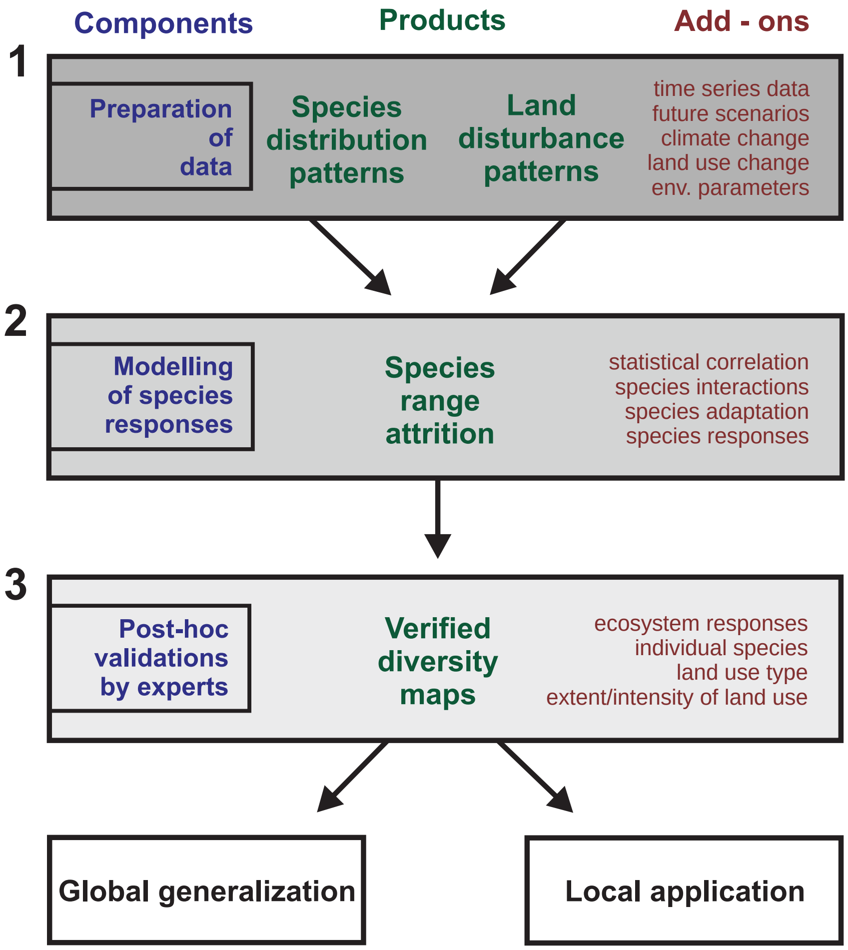


Figure 3.5: A hierarchical approach synthesizing the analyses of species responses to human land use activities. The pathway is divided into the three general steps building upon each other, with main components, products, and add-ons. As final results global generalization patterns and local application can be derived.

First, there is an essential need for the establishment of an extensive database of fine and detailed spatial information of potential species distributions and land cover/use data (Step 1). In the following, modelling of species responses to land use can estimate species range attritions and probable future scenarios (Step 2). Finally, results should be validated by expert opinions, incorporating knowledge of species responses to land use type and intensity, and as well as its changes (Step 3).

1. Database establishment. For many areas in the world comprehensive empirical species distribution datasets already exist. To fill remaining data gaps in poorly surveyed areas and to further determine the accuracy of species distribution ranges, the application of statistical modelling approaches is required. Statistical models, like environmental niche models are empirical approaches that are dependent on environmental parameters. Results are potential species distribution patterns.

Land cover has been observed by satellites at least since the early 1970s. The application of classified land cover data enables the estimation of land cover changes from the past to the present and helps to draw conclusions about the interaction of land cover and species occurrences. Dynamic land use models are based on environmental and socio-economic drivers. They are able to predict patterns and future demands of food and energy, and to identify the type of land management as well as the extent and intensity of land use.

2. Modelling species responses to land use. The intersection of distribution data and land cover and land use information is necessary to estimate species responses to land use. The observation of species distribution patterns by time series land cover data supports the estimation of changing species numbers. The loss of native habitats (as a result of an increase in land area converted to agricultural land) correlates with the attrition of species ranges. As an ordinary approach, statistical modelling, such as the species-area relationship, provides responses in the form of changing species numbers. Those approaches refer to species numbers within converted habitats compared to native habitats, without requiring any insight into ecological processes. By this, the dependence of species responses to respective ecosystems and several land use types is considered. For example, deforestation in tropical forest has a different impact on local biodiversity than cattle farming in grasslands. Statistical models, such as environmental niche models, allow for the integration of parameters that determine species habitats. This enables, for example, to estimate species distribution shifts due to dynamic climatic changes.

We suggest an improved understanding of the interactions between changing land use and species responses that is offered by the particular potential of process-based dynamic model approaches. These incorporate a combination of underlying ecological dynamics, determining how species interact with and adapt to a changing environment. The combination of these modelling approaches in addition to land cover and land use information enhance the knowledge of current and future species diversity patterns.

3. Post-hoc expert validations. Involvement of post-hoc expert validation of the results improves the previous statistical, dynamic and process-based modelling. Generalization of species numbers as well as differences between responses of individual species are necessary to be refined. For example, statistical modelling, such as the species-area relationship and environmental niche models, do not include any other species responses, such as the continued persistence in a converted land or an increase in range size as a result of native habitat gain. Experts are able to fill those lacks of knowledge by a post-hoc amelioration of the results. Currently, this aim is not yet achieved as required, and needs to be completely fulfilled.

Post-hoc expert knowledge assembled on coarse level generalizations provided by modelling approaches alone, may produce more precise outputs for policymakers and conservationists at the local level.

Outlook. The synthesis calls for the critical and expanding collaboration between the disciplines of remote sensing, ecological, statistical, and dynamic modelling, with post-hoc modifications of experts. This will improve quantitative predictions of spatial diversity patterns and future changes.

The suggested synthesis can help to fulfill the requirements, but further issues remain that will be disscused in the following section.

3.5 Discussion – remaining issues

Several approaches that represent a progress toward the integration of land use change and biodiversity responses were described, and it is highlighted that biodiversity changes are likely to be more complex than often assumed. Some of the analyzed approaches fulfill the amount of criteria set by the CBD, such as to be scientifically sound, usable for future predictions, and simply applicable. However, some of them are constrained by various issues leading to inconsistent and incomparable results, are still poor in information and not really helpful for estimating human induced biodiversity loss. We propose a synthesis that incorporates the main approaches, but some key limitations in this context still remain unsolved, such as data and modelling issues, as well as constraints in the application and implementation.

Data and modelling issues. Biodiversity datasets on large scales (continental or global) often have a coarse spatial resolution (see for example Thuiller, 2003; Pereira and Cooper, 2006; Barthlott et al., 2007). Reference areas of several kilometers can include a wide variety of land use types. Furthermore, fine resolution data are often scarce and local land use patterns too diverse, as limiting the ability to apply quantitative techniques at fine scales (Pimm and Lawton, 1998). The scaling issue makes models insensitive to land use change scenarios, consequentially causing problems interpreting biodiversity responses. The impact of land use on biodiversity differs relative to the spatial-temporal scale and level of aggregation (Whittaker, 1972). Models would benefit from the integration of a wider set of more specific variables referring to land conversion, fragmentation and degradation, land use types, intensity, and types of ecosystems. To obtain accurate species and land use data, conventional field-based techniques are indispensable, but are often very expensive and logistically difficult to conduct over large areas (Duro et al., 2007).

Another challenge is the estimation of future anthropogenic impacts on biodiversity, which are variable due to unknown future scenarios of land management. Management decisions strongly depend on social values, traditions, and experiences. The potential of improvements in agro-technology in the future is also highly uncertain (de Chazal and Rounsevell, 2009).

Constraints in application and implementation. Positive is that some approaches do satisfy the requirements set by the CBD to develop a scientifically sound, simply applicable, and broadly accepted indicator. But a single indicator for biodiversity loss can not account for the whole processes of biodiversity loss due to land use change. More indicators of biodiversity loss are needed to be determined, and valid models of biodiversity have to include the number of responses to the indicators (Scholes and Biggs, 2005; Balmford et al., 2005; Hui et al., 2008). In recent assessments, GLOBIO3 is virtually the only available tool able to assess possible consequences for biodiversity at the large scale (Alkemade et al., 2009). Nevertheless, the BII fulfills the criteria set by the CBD for indicators of biodiversity change to create a simple, sensitive, and robust indicator of biodiversity loss and is easily applicable to any region in the world (Mace, 2005; Hui et al., 2008). Even though some important points remain still elusive, the described studies indicate the best available approaches and are very helpful to address many urgent questions in the context of the CBD 2010 targets.

3.6 Conclusions

Summarizing a general result of all models discussed here, it is likely that the CBD target of *significantly reducing the rate of biodiversity loss at the global level* is not reached by the targeted year 2010 and will neither be reached in the near future. Most of the identified direct drivers of biodiversity loss are projected to either remain constant or to increase in the near future. It is a fact that biodiversity loss will not be stopped by more descriptive studies, and will not wait for the development of new approaches, or for the point where they can influence environmental policy. At the same time, species responses to environmental changes are complex and still not well understood. Therefore, we need decisive and precise estimations of the impact of global change on the current species status for safeguarding biodiversity and for setting conservation priorities. Several approaches already exist that aim to estimate the response of species to changing land use and climate variation. However, none of them delivers a scientific method that combines the effects of land use and climate change, and furthermore none is adequate for producing quantitative projections of future biodiversity patterns from current knowledge. The approaches have the potential to be improved and refined by the integration of species responses on land use such as adaptations of species, changes in species composition and interactions. An integrative synthesis demonstrates that many useful approaches already exist and are waiting for integration, application, and implementation. For that purpose, more collaboration between ecological modelers, remote-sensing researchers, and field biologists working in biodiversity science and conservation is necessary.

CHAPTER 4

Monitoring habitat loss of West African woody species: Integrating niche modelling and remote sensing

> *The global community is commited to reduce the rate of loss of biodiversity, but how can progress be measured?*
>
> Georgina M. Mace, 2005

Abstract. The integration of land cover change information considerably improves the outcome of classical species distribution models by delimitating habitat suitability for individual species and estimating the quality of habitats. The aim of the present study is to develop an integrative and applicable method to identify and monitor habitat quality loss. For that purpose potential distribution ranges of a set of woody species in West Africa were modelled based on geographic localities and environmental variables at a spatial resolution of 0.1 degrees. Potential ranges were weighted by the proportion of woodland cover to obtain actual distribution patterns. Results indicate a decline of overall habitat quality by 65% in the reference period from 1990 to 2000. In contrast, within protected areas, local habitat loss is overcompensated by a general improvement of habitat quality by 63%. The approach highlights the benefit of combining the expertise of two different disciplines, remote sensing and macroecology, for the evaluation of habitat quality inside and outside protected areas, and the spatially and temporally explicit monitoring of biodiversity loss.

4.1 Introduction

Human-induced habitat loss represents the largest current threat to biodiversity (Chapin et al., 2000; Menon et al., 2001; Gaston, 2005), accompanied by fundamental changes in ecological functioning (MEA, 2005; Laurance and Luizao, 2007). During the past decades human population growth and the intensification of land use have increased the pressure on forest habitats (Wilkie and Laporte, 2001; Poorter and Bongers, 2004). Land cover changes, such as conversion of forest and woodland areas to agricultural land, continues at an increasing rate (FAO, 2006). The high tree diversity of West Africa, as a natural resource and a basic foundation of the livelihood of the region's inhabitants, is declining in many places (Balmford et al., 2001). For West Africa studies of Chatelain et al. (2001) and Poorter and Bongers (2004) estimate that only about 20 to 50% of the forest habitats, which existed at the turn of the 19th century, are still intact.

Analyses of the current quality of habitats are essential in order to better understand the impact of environmental change and the need for the development of sustainable management policies. Geographic distribution of physiognomic vegetation types such as forest and woodland, can be used as an indicator for habitat change. For that purpose, their actual distribution ranges have to be determined. In contrast to the native species distribution range (*potential*) without any changes of suitable conditions, we define the *actual* species distribution range as the suitable area that is shaped by natural or human induced land cover changes. Comparing *potential* and *actual* individual species distribution indicate information about habitat loss and performed for a number of species, the actual patterns of plant species richness.

Potential distribution of individual species are described by environmental requirements that provide basic input for environmental niche model approaches (Guisan and Zimmermann, 2000; Scott et al., 2002). The *potential* distribution range of the species is described by the variance of these parameters. Areas with corresponding environmental conditions to those at the species' occurrences are considered as suitable potential habitats (Guisan and Zimmermann, 2000; Hunter, 2003; Phillips et al., 2006; Phillips and Dudík, 2008). It is widely accepted that those models are capable of filling the gaps in the documented distribution of species (Saatchi et al., 2008). These models are a critical tool for understanding the effect of environmental variables on *potential* species distribution (Saatchi et al., 2008), but they do not predict *actual* distribution ranges.

The demand for *actual* information about vegetation cover has created the need for collecting data over large regions using advances in remote sensing (Turner et al., 2003;

Gillespie et al., 2008). Time series of satellite data can be used to locate temporal changes in land cover. These approaches require an quantifiable accurate classification of land type from image data (Foody and Cutler, 2006). Results deliver estimates about land cover, but do not measure habitat suitability according to environmental requirements of respective species. For example, deforestation can reduce the extent and the change of suitability of *potential* habitats of many species (Bradley and Fleishman, 2008).

The primary aim of the presented approach is to combine high resolution land cover information with the environmental niche modelling approach to approximate *actual* habitat suitability of species distribution. It is an enhancement of the classical environmental niche modelling, and it is reproducible for any type of spatial and temporal distribution data. We present maps of the habitat quality for representative woody species and analyze its improvement and decline inside and outside protected areas in the reference period from 1990 to 2000. This allows to draw conclusions about how many and which particular species are potentially endangered or already extinct. Following hypotheses concerning the conservation of species can be framed:

- Actual distributions of plant species have a smaller extent than potential.
- A change of pristine land cover causes a loss of habitat suitability for plant species.
- Natural and human-induced land cover changes cause local current extinction risks.

The approach highlights the benefit of combining the expertise of two different disciplines, remote sensing and macroecology, for the spatially and temporally explicit monitoring of biodiversity loss.

4.2 Methods

Study area – West Africa

We examined changes of West African woodlands at the extent of the Volta river basin (5°12 North, 15°21 North, 6°8 West, 3°40 East), including parts of Ivory Coast, Ghana, Togo, Benin and Burkina Faso (Figure 4.1). This represents an area of roughly 700,000 square kilometers. Our study area covers a wide variability in climate and topography, and it reflects many aspects of vegetation cover and land use activities. The analyses were performed at a spatial resolution of 0.1 degrees, dividing the study area into 6,735 grid cells of approximately 100 square kilometers each.

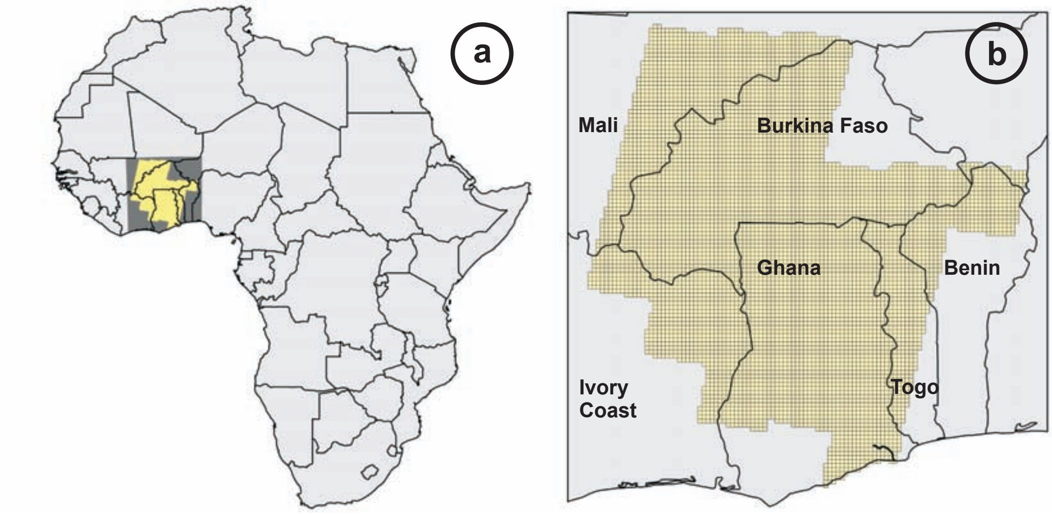


Figure 4.1: (a) Study area and working mask (yellow) including 6735 grid cells (each of approximately 100 square kilometers) in Africa, and (b) extent of the model area (gray).

Plant data – modelling potential distribution

A joint database on West African plant species distribution localities was established in the frame of the BIOTA West research network and managed by the BIOMAPS working group at the Nees Institute, University of Bonn, Germany. Collection points originated from herbarium specimens either direct or taken from taxonomic revisions, and digitized distribution maps.

Records are dated over a time period of approximately 80 years. All are available at a grain size of 0.1 degrees. Out of this unique data collection we concentrated on documented records of representative woody species. This type of vegetation represents a physiognomic indicator group to the according woodland cover class with leaf cover from 15% up to 100%. The congruence of the species was confirmed by several bota-

Table 4.1: Selected West African woody species that exemplarily represent the congruence to West African woodlands, species family affiliation, and the number of samples used for modelling potential plant distribution.

Species	**Family**	**Number of samples**
Anogeissus leiocarpa	Combretaceae	66
Daniellia oliveri	Leguminosae	42
Isoberlinia doka	Leguminosae	40
Isoberlinia tomentosa	Leguminosae	20
Khaya senegalensis	Meliaceae	31
Lophira lanceolata	Ochnaceae	33
Monotes kerstingii	Dipterocarpaceae	34
Terminalia glaucescens	Combretaceae	24
Terminalia laxiflora	Combretaceae	55
Terminalia macroptera	Combretaceae	33
Terminalia mollis	Combretaceae	27

nists studying in West Africa. We selected eleven plant species with samples that are randomly distributed and differ from 20 to 66 within the model area (Table 4.1).

For modelling potential distribution ranges a species-based environmental niche model (Maxent – Maximum entropy probability distribution model) was applied. Maxent is a general-purpose algorithm that generates predictions or inferences from an incomplete set of information. It is based on a probabilistic framework (Phillips et al., 2006). For the calibration of the model twelve environmental parameters were used, comprising two variables regarding topography, four for precipitation, and six for temperature (Table 4.2). Data available at a spatial resolution of 0.01 degrees were rescaled to mean values to 0.1 degrees and integrated into the model. To obtain a higher accuracy of prediction, the model area is a superset of the study area (Figure 4.1), comprising more species collection points and a wider range for environmental conditions compared to the working mask. As output, the probability values for potential occurrence for each species per 10 × 10 km grid cell were generated. To transform the results of distribution modelling from probability of occurrence to absences and presences three thresholds were determined (Liu et al., 2005): the *prevalence approach* (taking the prevalence of model building data as the threshold), the *average probability approach* (taking the average predicted probability of the model-building as the threshold), and a *fixed threshold approach*. All were tested by Liu et al. (2005) as useful models with good predictions. In further analyses we used the *average probability approach* as it gives the most consistent results of these three thresholds. The *prevalence approach* overestimated and the *fixed threshold* underestimated the predictions.

Table 4.2: Environmental parameter (0.01 degrees) used for modelling species distribution ranges, all derived from Hijmans et al. (2005).

Parameter	Description
Topography	Elevation
Topography	Variance of elevation values (SRTM30) within a 9x9 moving window
Precipitation	Standard deviation of the 12 monthly precipitation data
Precipitation	Maximum of the 12 monthly precipitation data
Precipitation	Minimum of the 12 monthly precipitation data
Precipitation	Sum of the 12 monthly precipitation data
Temperature	Minimum of the mean monthly minimum temperature
Temperature	Maximum of the mean monthly minimum temperature
Temperature	Standard deviation of the mean monthly minimum temperature
Temperature	Minimum of the mean monthly maximum temperature
Temperature	Maximum of the mean monthly maximum temperature
Temperature	Standard deviation of the mean monthly maximum temperature

The revised presences of each species were superimposed to obtain a map of potential species richness. Results were combined with remote sensing data to estimate actual distribution patterns. The methods used will be explained and discussed in the following.

Integrating remote sensing data – advantages and uniqueness

We received land cover data of West Africa from BIOTA West project partners at the Remote Sensing Unit of the Institute for Geography, University of Würzburg, in cooperation with the DLR (German Aerospace Center).

Land cover data were derived from cloud free 30-60-meter Landsat MSS/TM/ETM+ tiles from 1990 and 2000 and from 250-500-meter 16-days MODIS satellite composite metrics data (Zhang et al., 2005; Colditz et al., 2006; Landmann et al., 2008). These data were classified using standardized land cover classifications (Gregorio and Jansen, 1998; Lambin and Linderman, 2006; Landmann et al., 2008) into 10 categories (Figure 4.2): (1) Forest, (2) Woodland, (3) Shrubland, (4) Grassland, (5) Agriculture, (6) Bare ground, (7) Burned areas, (8) Urban areas, (9) Water, (10) Wetland. For simplicity, we focused attention on classes characterizing woodland types and classified all pixels with a leaf cover from 15% up to 100% as one woodland cover category.

To combine these data with modelled plant distribution ranges, the woodland cover at a spatial resolution of 250 meters had to be rescaled. Therefore, the percentage of wood-land cover of 1600 pixels per each 10 × 10 kilometers grid cell was calculated to maintain the maximum of information. Non-woodland pixels contain information

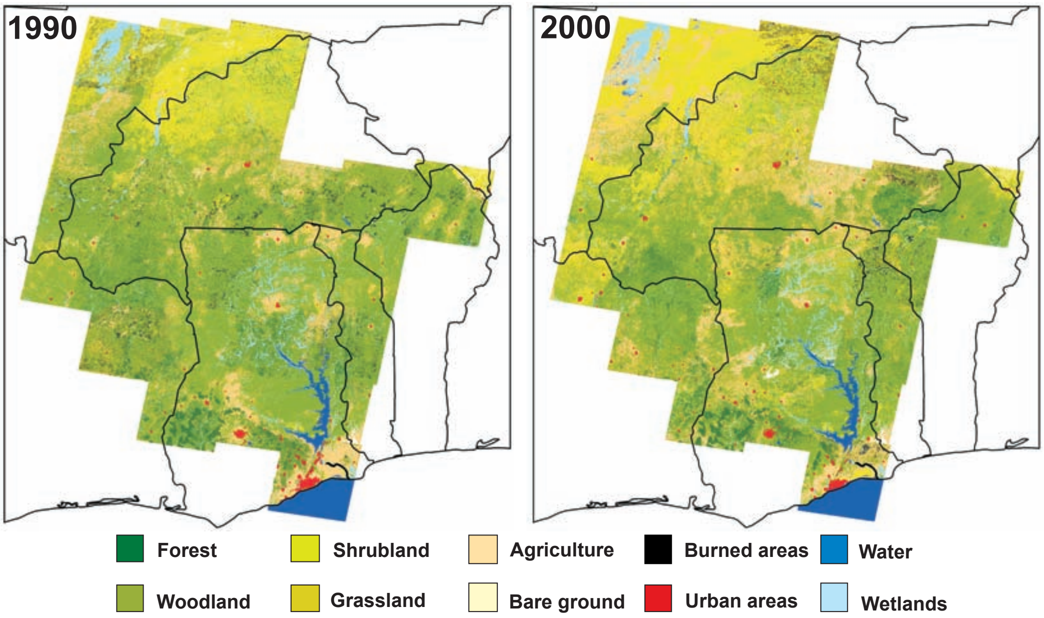


Figure 4.2: High resolution land cover data (at a spatial resolution of 250 m) for 1990 and 2000 illustrated in ten categories. Data processing and classification: Remote Sensing Unit of the Institute for Geography, University of Würzburg, in cooperation with the DLR (Landmann et al., 2008).

about non-woodland cover categories, such as shrublands, grasslands, agriculturally used areas, wetlands, bare ground or sparsely vegetated, urban areas, water surfaces, and burned areas.

This upscaling method smooths minor errors in the data and the accumulated error is expected to be small. Quantitative information about woodland cover per 10 × 10 kilometers grid cell were obtained. Values between 0 and 1 describe the proportion of woodland cover per grid cell for 1990 and 2000. We calculated the change of woodland cover between 1990 and 2000. In the following analyses these data were used to evaluate the actual habitat suitability and the change of habitat quality.

Actual habitat suitability – constraining potential species distribution

The overarching consideration is that in areas without woodland, the probability of the selected representative woody species occurrence is 0 (i.e. no species occurrence), as we selected species that only occur in woodland systems (Chapter 4.2). The percentage of the extracted woodland cover was used to weight potential species occurrences per grid cell using equation 4.1. These analyses were performed at a spatial resolution of 10 × 10 kilometers based on the spatial resolution of plant species records.

For each grid cell i we calculated:

$$H_a^i = H_p^i w^i, \tag{4.1}$$

where

$$w^i = \frac{n_{\text{woody}}^i}{n_{\text{total}}}, \tag{4.2}$$

with

H_a^i = Species actual suitability per grid cell,
H_p^i = Species potential suitability per grid cell,
w^i = Woodland cover percentage for grid cell i,
n_{total} = Number of pixels per grid cell (1,600), and
n_{woody}^i = Number of woodland pixels in grid cell i.

The actual habitat suitability H_a is derived from the potential environmental suitability H_p weighted by the percentage of woodland cover w and was calculated per grid cell i. The proportion of woodland is given by the number of pixels n_{woody} with woodland cover divided by the total number of 250m-pixels n_{total} per cell. This has been applied for all grid cells (6735) inside the study area. The results indicate that the grid cell is predicted to have suitable conditions for the particular species and is an indicator for habitat quality. Woodland cover was used to constrain the potential habitats of modelled species distribution ranges. The results are estimations of actual occurrence of woody species affected directly by woodland cover. Revised presences of each species were superimposed to obtain a map of patterns of current species numbers.

Monitoring the habitat quality of woody species

The change of habitat was calculated by subtracting the habitat suitability of both time steps from each other. Quality maps were obtained indicating the change of habitat suitability of the representative woody species. Results were compared with the patterns of polygons representing protected areas downloaded from the World Database of Protected Areas (WDPA), incorporating the UN List of protected areas (Chape et al., 2005; Arce, 2009).

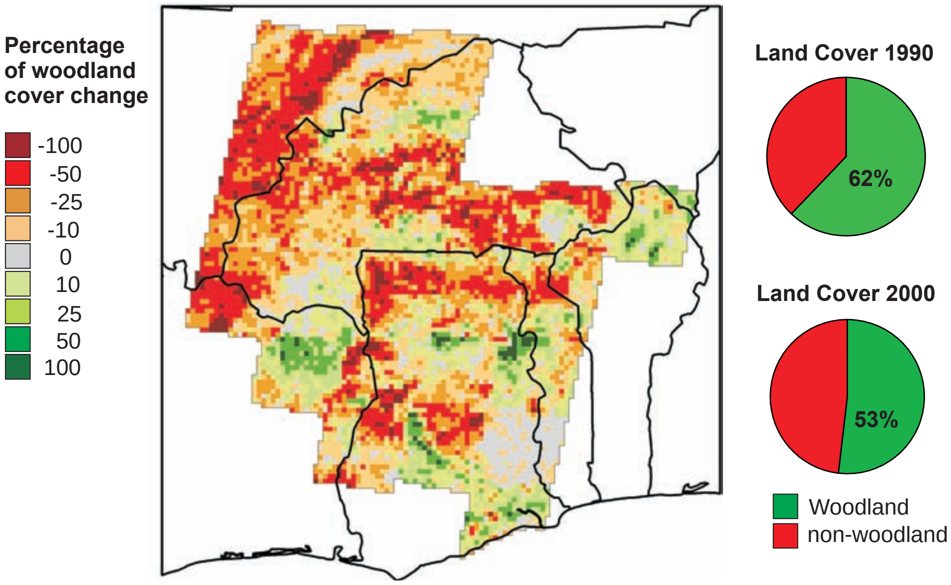


Figure 4.3: Loss (graduated red) and gain (graduated green) of woodland cover between 1990 and 2000 at a spatial resolution of 10 × 10 kilometers are mapped. The pie charts indicate the portion of woodland (green) and other land cover classes (red) for each year inside the study area. Change of woodland cover are derived from Figure 4.2.

4.3 Results

Woodland cover change between 1990 and 2000

Referring to the study area the percentage of woodland cover predominantly decreased from 62% in 1990 to about 53% in 2000 (Figure 4.3). The most prominent centers of woodland loss are located in the north to north-west of the study area, in the center of Burkina Faso, and in the northern and western of Ghana. Analyzing the entire study area, the mean woodland loss between 1990 and 2000 surpasses 21% (in 4392 grid cells), and the mean woodland improvement is less than 16% (in 1721 grid cells).

Potential distribution of representative West African woodland species

For each species a map of probability of occurrence was obtained (Figure 4.4, 4.5, 4.6). The evaluation and validation with published distribution patterns of species and the expertise of come West African botanists indicate an accuracy of our predictions. Results were superimposed and presented as a species richness map (Figure 4.7). Species ranges overlap in most regions, remarkably in the north of Benin, the south-west of Burkina Faso, and the north of Ghana where all species find the same suitable conditions.

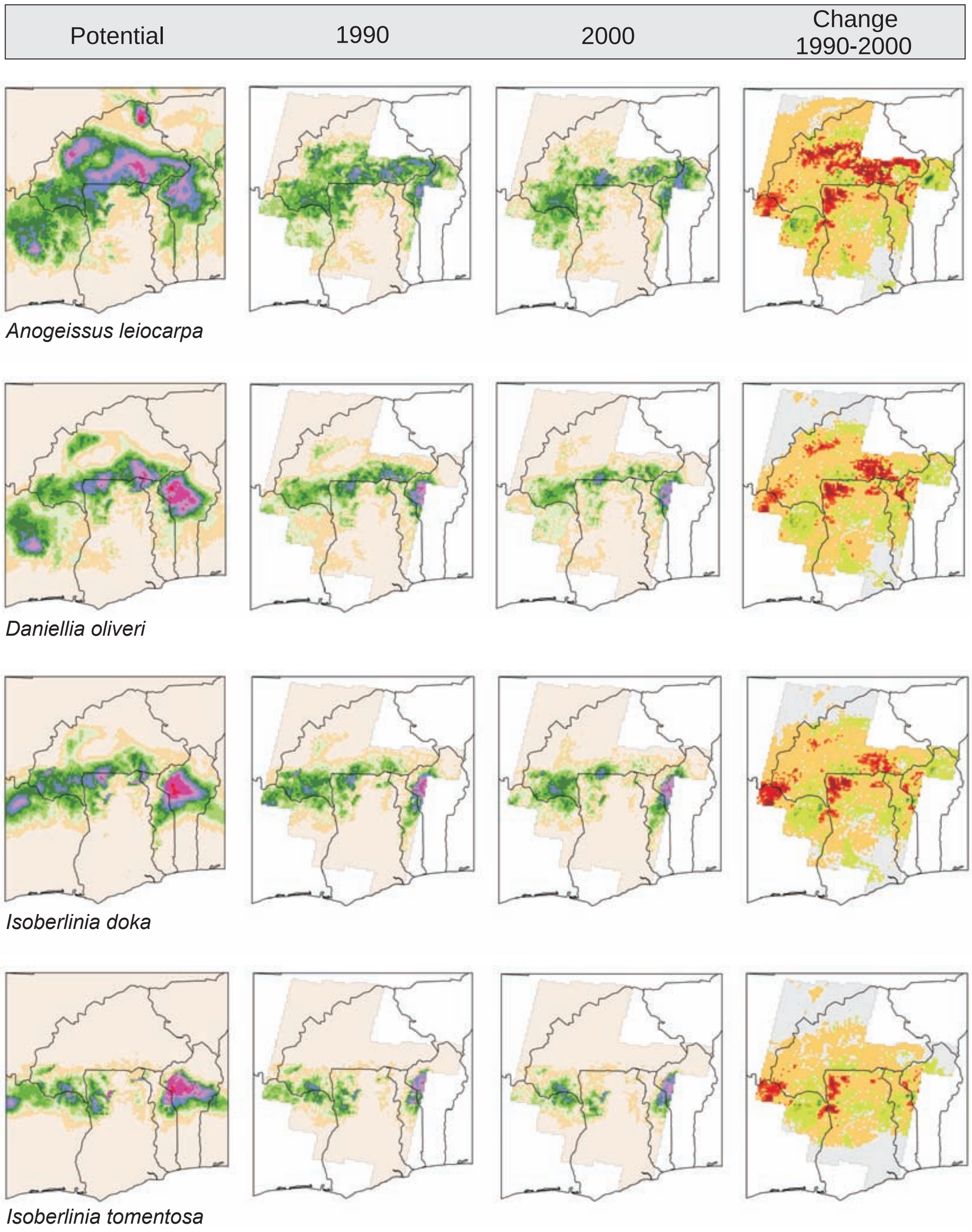


Figure 4.4: Estimated potential and actual plant species distributions in probabilities values for the year 1990 and 2000 and its change per species. The model was performed at a spatial resolution 0.1 degrees (1).

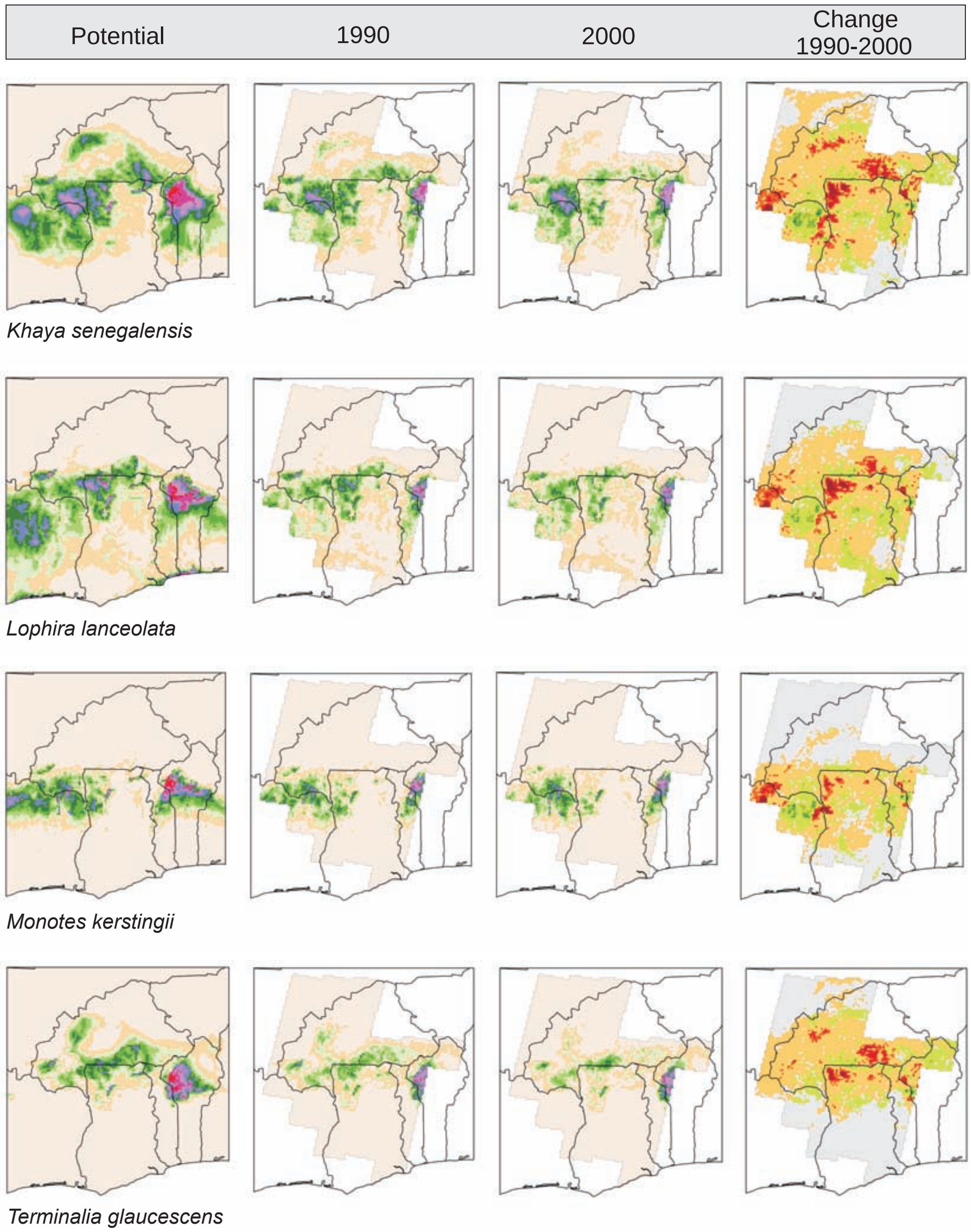


Figure 4.5: Estimated potential and actual plant species distributions in probabilities values for the year 1990 and 2000 and its change per species. The model was performed at a spatial resolution 0.1 degrees (2).

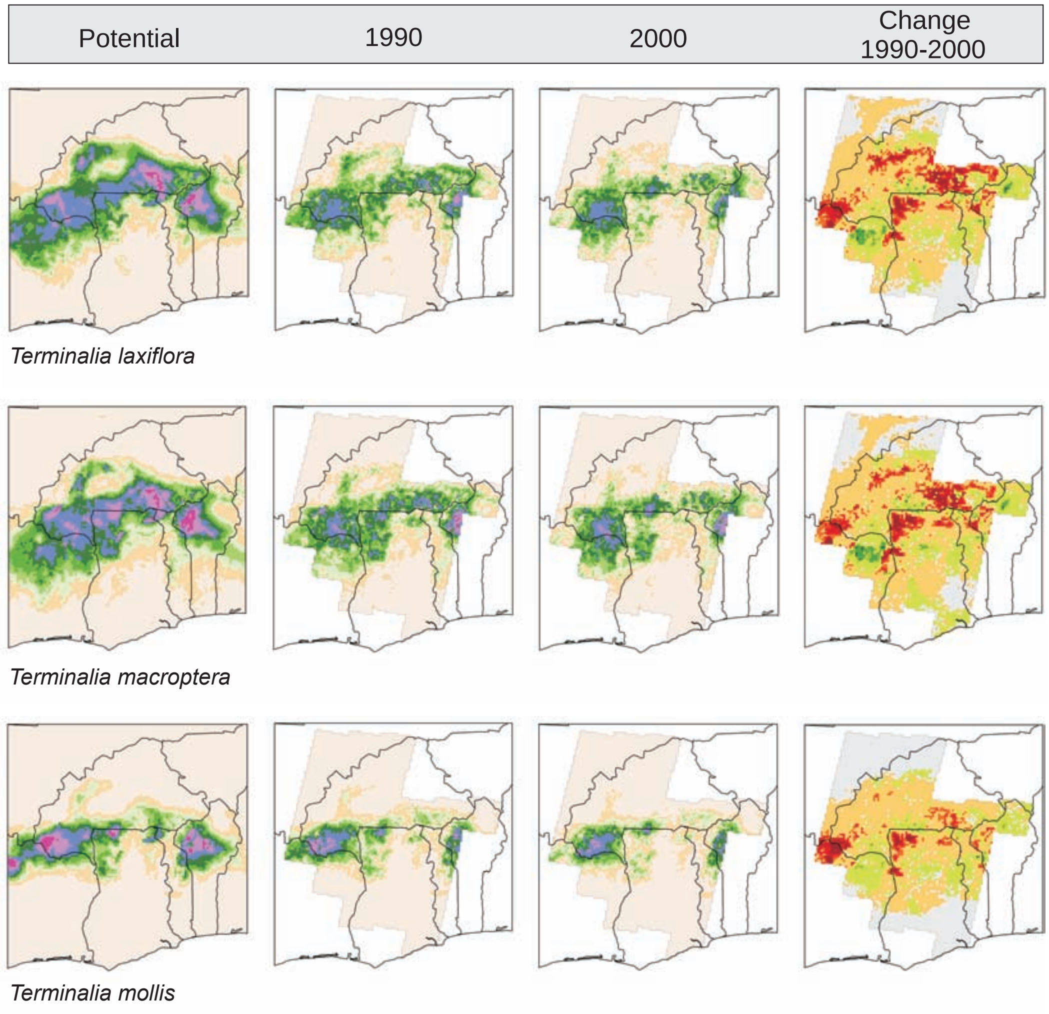


Figure 4.6: Estimated potential and actual plant species distributions in probabilities values for the year 1990 and 2000 and its change per species. The model was performed at a spatial resolution 0.1 degrees (3).

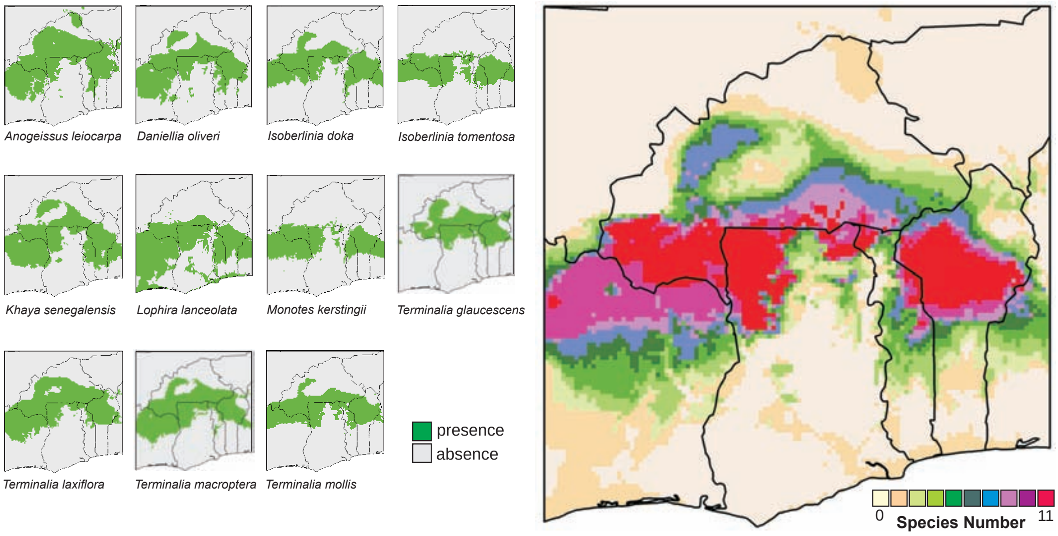


Figure 4.7: Potential species distribution ranges are based on distribution records (left figures), and are displayed as presences (green) and absences (gray). Potential plant species numbers are based on superimposed modelled geographic presences and absences of eleven representative woody plant species congruent to the West African woodlands at a spatial resolution of 0.1 degrees (right figure).

Revised distribution patterns

Revised distribution patterns reflect the combination of woodland cover and potential distribution areas. Potential species distribution become constraint, and may be interpreted as the actual distribution patterns in 1990 and 2000. Species do not occur in areas with unsuitable environmental conditions and decrease with the continuous decrease of woodland cover (for results for 1990 see Figure 4.8 and for results for 2000 see Figure 4.9).

Potential range sizes of all species differ significantly from the modelled ranges of the years 1990 and 2000 (Figure 4.10). The mean decrease of all species potential ranges to the year 1990 is 24%, and the mean decrease of potential to the year 2000 is 36%. Between the years 1990 and 2000 the mean range size decreases by 12%.

Habitat change – conservation status of protected areas

Modelled distribution patterns for the reference period from 1990 to 2000 indicate a habitat change of species, due to woodland cover decrease or increase. The habitat quality of woody species increases in 16% of the study area, but decreases in 65% (Figure 4.11). In contrast, within protected areas an improvement of habitat quality can be observed in about 63% of the area, and a decline of 21% of habitat quality of the area.

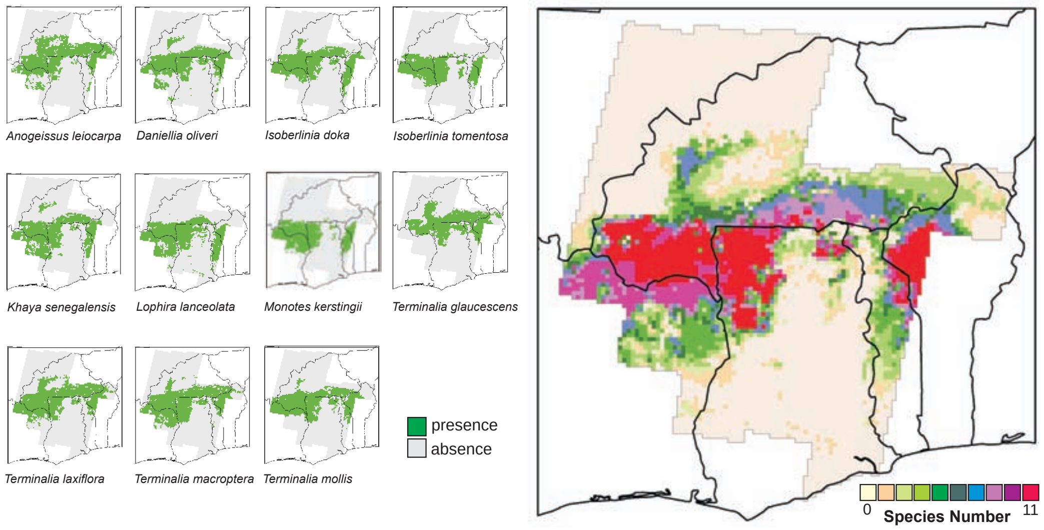


Figure 4.8: Revised actual species distribution ranges displayed (left figures) as presences (green) and absences (gray), based on potential ranges combined with woodland cover data of 1990. Actual plant species numbers are based on superimposed revised geographic presences and absences of eleven representative woody plant species congruent to the West African woodlands at a spatial resolution of 10 × 10 km based on woodland cover data of 1990 (right figure).

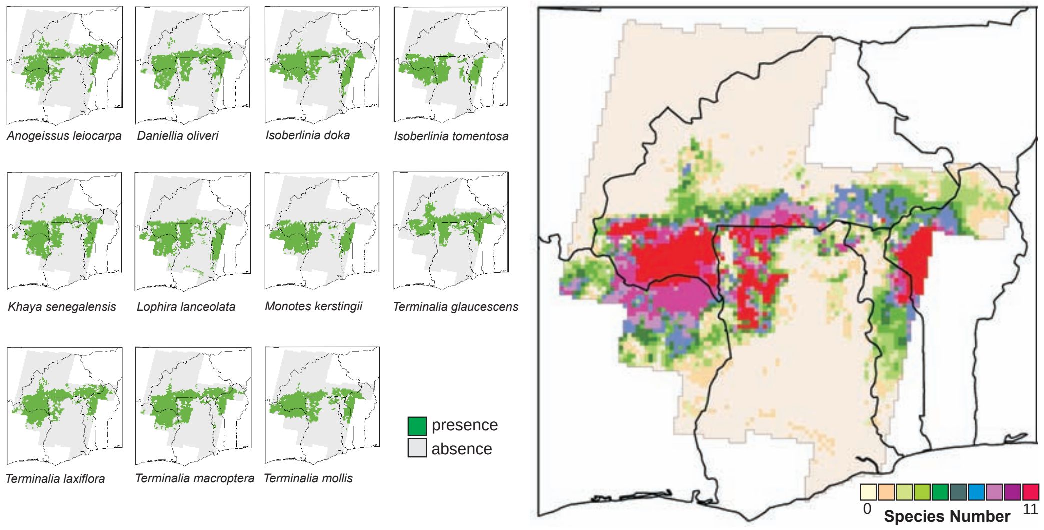


Figure 4.9: Revised actual species distribution ranges (left figures) displayed as presences (green) and absences (gray), based on potential ranges combined with woodland cover data of 2000. Actual plant species numbers are based on potential distribution modelling and superimposed geographic ranges of eleven representative woody plant species congruent to the West African woodlands at a spatial resolution of 10 × 10 km based on woodland cover data of 2000 (right figure).

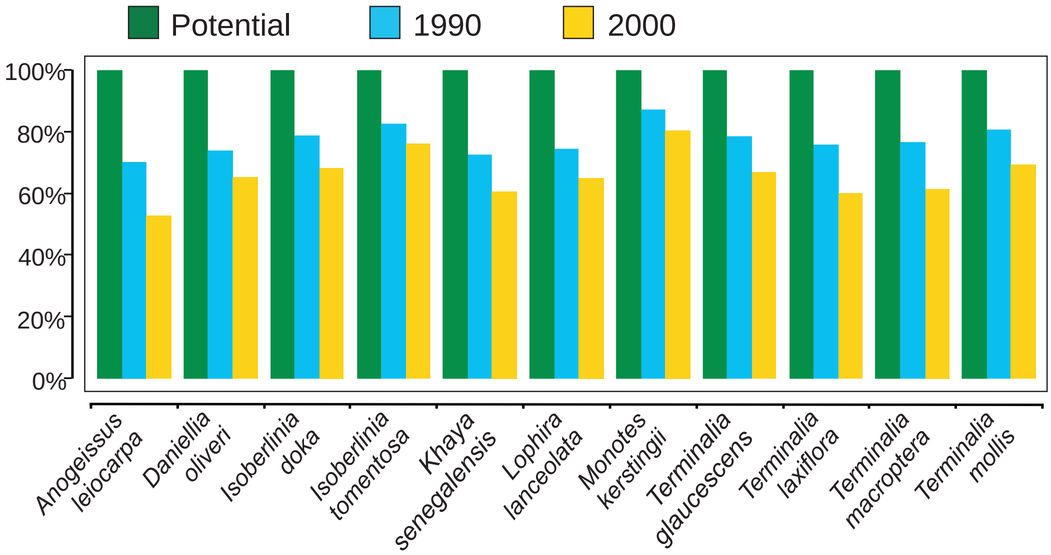


Figure 4.10: Differences between potential ranges of representative plant species of West African woodlands (green), distinguished to actual species ranges in 1990 (blue) and actual species ranges in 2000 (orange).

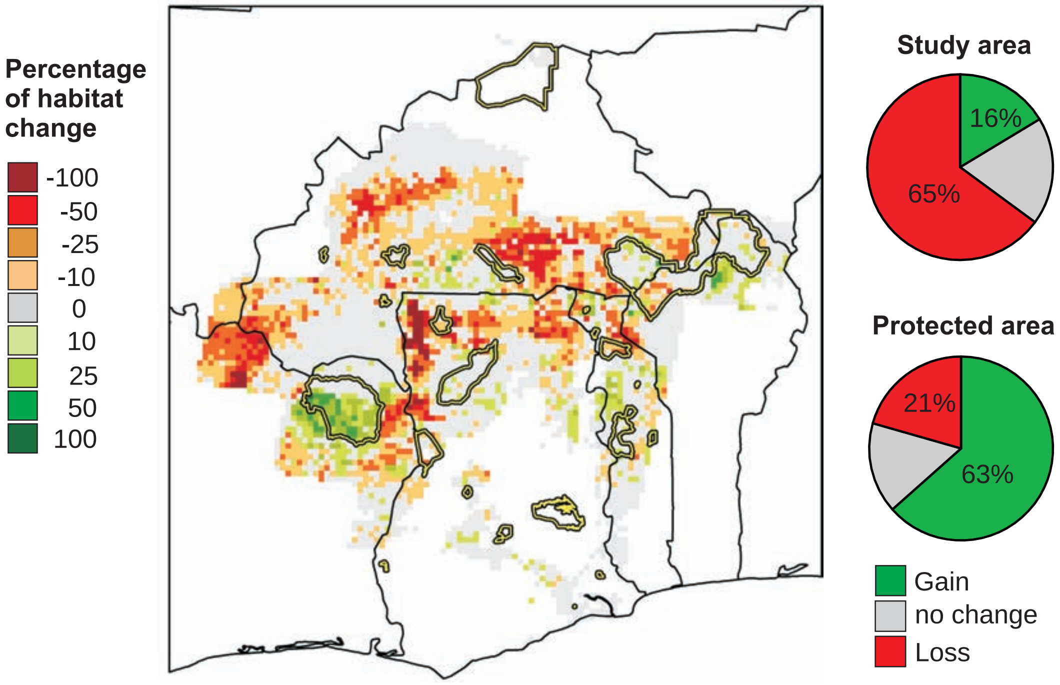


Figure 4.11: Change of habitat quality between 1990 and 2000 of representative woody plant species of West African woodlands, presented as decrease (graduated red) and increase (graduated green) of suitable habitats inside and outside protected areas (yellow borders) at a spatial resolution of 10 × 10 km. The pie charts show the portion of improvement (green), loss (red), and no change (gray) of suitable habitats between 1990 and 2000 inside and outside protected areas.

4.4 Discussion

This study introduces a modelling approach that integrates classical species distribution modelling and remote sensing data. This integrative approach is easily applicable and repeatable for many of plant species and can be related to explicit land cover data. It can be seen as an improvement of the classical approach that estimate actual species numbers and diversity patterns. Using representative woody species of West African woodlands as indicator, this method allows the monitoring of species habitat changes.

The potential of applying remote sensing data

Our study the need for remote sensing in conserving, monitoring and evaluating biodiversity inside and outside protected areas. On the one hand remote sensing information can be used to model species richness patterns (environmental parameters), and on the other hand remote sensing has the potential to locate endangered areas directly (land cover data) (Schulman et al., 2007). Remote sensing may be used to monitor a habitat by focusing on single land cover classes of explicit interest (Gillespie et al., 2008).
Species communities are complex and interdependent networks, and the actual response of species to a shift in woodland cover is difficult to predict. However, it is possible to estimate species occurrence by woodland cover data. In our model we compare patterns of land cover and modelled distribution ranges to qualify species habitats.

Advantages in using an integrative approach

Environmental niche models are an accepted tool for modelling species distributions. In the example of classical distribution modelling environmental variables are used to determine potential occurrence of plant species. This approach implies that environmental conditions (topography and climate) in which the species were found are much the same today as when they were collected. But this is not true for woodland cover that can be modified by human activities during a few years. The use of land cover data, such as detailed woodland cover information, as a parameter describing potential habitat of a plant species, is not advisable: Woodland cover (and land type in general) is rapidly changing, whereas the species sample data we use have been collected over the course of a century. If we include correlations of species sample locations with respect to *today's* land cover, we may conclude that woodland species prefer conditions in urban areas – because the areas are urbanized today. It appears more reasonable dedicate species to particular land cover types, with the help of available expert botanical knowledge.

This facilitates to post-process the modelled distribution result by integrating woodland cover data. Furthermore this approach enables to quantify the threat to plant habitats caused by land cover changes during a ten-year time period and over a large spatial extent.

Preparing data – scaling issues

Our analyses were carried out at a spatial resolution of approximately 10 × 10 kilometers, determined by the plant data, which are available at a spatial resolution of 0.1 degrees. The modelled distributions of species refer to environmental parameters that reflect mean values for 10 × 10 kilometers grid cells. Hence the model does not consider any finer resolved environmental patterning. In general this will lead to an overestimation of modelled species range size. As we selected representative woody species for our analyses, a misinterpretation of the actual environmental requirements of species is possible (e.g. in the case of species occurring only in woodlands). On the other hand the environmental pattering below the resolution of the models in most cases provides a wider array of environmental conditions within each grid cell than is covered by the mean values of parameters per 0.1 degrees grid cell.

To make land cover data and modelled plant distribution data compatible, the common finest scale (10 × 10 kilometers) was used. Fine scale woodland cover data were reduced to the proportion of woodland per grid cell. By this we lose spatial information, but we obtain quantitative information about woodland occurrences. This method can be used in general to rescale high resolution data, if (1) the spatial pixel information is not essential (for an up-scaling), (2) proportion of land cover classes can be used to evaluate grid cells by quantity, and (3) categorical (not continuous) information is available. The accuracy of our land cover data depends on seasonal dynamics such as dry or wet periods, on the quality of satellite images, on the effective point of time of satellite imaging and of the classification methods. Resulting difficulties of describing land cover, especially woodland cover, can be reduced by the methods described above. By taking only the percentage of the 1600 pixels per cell that represent woodland cover, minor errors in the data are smoothed and the accumulated error is expected to be small. However, the land cover data are not accurate enough to give evidence about individual spatial patterns of land cover, but are sufficient to describe a trend in woodland cover change. This applies for example to the examination of the success protected areas.

Deforestation - change of habitat suitability

Woodland cover decreases in the reference period by around 9% supposedly due to deforestation. Our analyses assume an overall decline of species habitat suitability by 65%. These results indicate that a general decline of woodland can have high impact value on plant habitats, as their suitable environmental conditions (such as an undisturbed woodland cover) get limited.

Most areas of West Africa dramatically decline in habitat quality. In contrast, referring specifically on protected areas, a general improvement of habitat quality was determined. This allows us to qualify protected areas as providing a long lasting protection and a chance for reforestation of woody species.

Human population pressure is one of the most important factors explaining the decline of tree cover that comes with logging and the expansion of cropland areas (Achard et al., 2002; Lambin and Linderman, 2006). Most of the rural populations rely heavily on wood for fuel and therefore as the local population increases, the demand grows much faster than forest regeneration can occur.

4.5 Conclusions

Despite methodological limitations and serious gaps in knowledge, the application of an integrative approach enhances the evaluation of biodiversity patterns demonstrated by the combination of the expertise of two different disciplines. The incorporation of classical environmental niche models and land cover data show the potential to deliver estimations of the actual species distribution. Consideration of land cover information drastically delimitates the modelling results of the distribution of potentially suitable habitats. Besides the approximation of actual species distribution, further consequences on the overall habitat quality can be delivered. We showed exemplarily for West Africa that habitats suitable for woody species predominantly decreased during one decade, and are under severe land cover change-induced threat. Between 1990 and 2000, the size of suitable habitats of woody species predominantly decreased due to woodland cover changes. This demonstrates the potential of the developed approach to identify areas where land cover changes and centers of biodiversity coincide and, equally important, over which time-span these changes occur. Is it a long term or a short term process of change and what is causing the change? In this terms the approach of integrating land cover information into species distribution modelling can be used as a spatially and temporally explicit monitoring tool. Thereby it enables the identification and monitoring of natural resources such as native forest cover. Moreover, it allows the evaluation and qualification of the status of protected areas with respect to their current significance for conservation. As an outlook, in addition to the quantification of deforestation, the integration of socio-economic factors would enhance its understanding. In that context, based on actual land cover patterns dynamic models facilitate the projection of future habitat dynamics. Processes of land cover change may be allowed to be analyzed and understood. The application of such factors can help to identify related challenges in agriculture policy, the plantation economy, intensive agricultural production and the land right system.

Acknowledgements

This study is based on a joint database on West African plant species distributions and was established in the frame of the BIOTA West research network. In this context, we acknowledge the contributions of G. Zizka (Senckenberg, Frankfurt), C. Chatelain (Jardin Botanique de Genève, Switzerland), A. Thiombiano (Université de Ouagadougou, Burkina Faso), R. Wittig (University Frankfurt), M. Schmidt (Senckenberg, Frankfurt), and K. König (University Frankfurt).

CHAPTER 5

Current and future land use threats to African plant diversity

> *When I hear of the destruction of a species, I feel just as if all the works of some great writer have perished.*
>
> Theodore Roosevelt, 1906

Abstract. Land use change is one of the key drivers of species loss. Across continental Africa, habitat conversion, fragmentation, and destruction cause severe reductions of species distribution ranges. This urgently calls for conservation strategies that take into account current and future land use threats. This study analyses distribution ranges of 3,144 vascular plant species in respect to their proportion of converted habitats. The potential distribution of the ten percent of species with most severely converted habitats were located in order to determine current and future centers of extinctions. The average land use-induced constriction of potential distribution ranges is projected to increase from 37% in 2000 to an expected 44% in 2050. Today, land use activities predominantly affect range-restricted species. By assuming a future expansion of land use, habitats of more wide-spread species may additionally be affected. This approach yields reliable insights into the spatial and temporal impact of land use on species persistence.

5.1 Introduction

Land use - as the direct anthropogenic intervention in nature - is considered as the major threat to global biodiversity in terrestrial ecosystems (Sala et al., 2000; Laurance et al., 2001; MEA, 2005; Feeley and Silman, 2009). The expansion of agricultural areas causes a rapid conversion, fragmentation and destruction of native habitats and a severe risk of endangerment and extinction of species in the past, present and future (Rebelo and Siegfried, 1992; Richardson et al., 1996; Rouget et al., 2003b; Latimer et al., 2004; Ellis and Ramankutty, 2008).

The IUCN (International Union for Conservation of Nature) has been assessing the conservation status of species on a global scale in order to highlight taxa threatened by extinction and to promote their conservation (IUCN Red List of Threatened Species™) (Hilton-Taylor and Mittermeier, 2000). In order to assess conservation priorities it is important to identify the threat status of species and further to locate regions with high numbers of threatened species. This is usually based on current distributions, population sizes and past declines of populations, while future threats such as the development of land use, remain largely disregarded (Bomhard et al., 2005). The consideration of an expansion of land use areas would result in a substantial change of the threat status of species and is a challenge for future conservation plannings (Burgman, 2002).

Basic gaps in ecological knowledge make it difficult to predict how populations will respond to land use change. Species may respond sensitively with a decline or positively with an increase of populations, or exhibit no change to land use activities. There is evidence at a broad spatial scale that species richness tends to decline with agricultural intensification (MEA, 2005; Scholes and Biggs, 2005; Perfecto et al., 2009). This general assumption is a conclusion of several studies that actually ask this research question depending on taxon and management intensity of land use. The rate of biodiversity change according to the intensity of land use is still unclear. Agriculture is invariably implicated in the process of conversion, fragmentation and the destruction of native habitats (Pimm et al., 1995). Environmental changes lead to immediate, serious risks for plant species such as the reduction in the total area of the suitable habitat, an increase in the amount of boarder regions (edge-effects) and the isolation of habitat fragments from other areas of suitable habitat (Haila, 2002).

Any intrusion into native habitats may change the distribution range of a species, dependent on ecological and evolutionary characteristics (Gaston, 2003, 2008). Reduction in range size through time is a strong predictor for the extinction risk of a species (Thomas et al., 2004; Purvis et al., 2000b). Remaining areas and its fragments are often too small to support viable populations (Turner, 1996; Ferraz et al., 2003).

The assessment of geographical distribution ranges starts from sampling species distribution data (specimens), together with their geographic location and environmental variables. As one possibility, distribution data can be used to approximate potential range sizes by the use of statistical modelling approaches. Hereby, typically locality data (presence data) are combined with data on the spatial variation of environmental parameters (Thuiller et al., 2005b; Pearson et al., 2006; Phillips and Dudík, 2008). The general assumption is that species are likely to be present in similar environmental conditions to those where they were found. The resulting species ranges therefore indicate *potential* rather than *actual* distribution patterns (Harte et al., 2001; Soberon, 2005; Phillips et al., 2006; Gaston, 2008). An estimation of *actual* distribution ranges incorporates data on current habitat conversion such as land cover or land use changes, and is useful to determine proportions of converted species habitats. This method is presented here.

We develop a quantitative approach to estimate the conversion of current and future plant habitats and their spatial distribution in continental Africa. The central hypothesis that motivated this study is that land use, in the form of habitat conversion, results in a reduction of potential range size. We state the following assumptions:

- Land use activities comprise habitat destruction, fragmentation and conversion.
- Species geographic range size is reduced by land use activities.
- The threat on a certain species increases with a reduction of species range sizes.
- Land use change is a threat on species persistence.

This study aims to locate the current threat of land use on vascular plant species in Africa and how patterns may change according to a plausible land use scenario by the year 2050.

5.2 Methods

Study area

The African continent covers a wide variety of abiotic and biotic conditions. The vegetation varies from humid rain forests in the Central Congo Basin to the arid desert and savanna regions in the Sahel. The high diversity in ecological parameters and a multitude of socio-economic factors result in a variety of different land use practices and dynamics. For our analyses we used a spatial resolution of 0.5 degrees, dividing the study area into 10,864 grid cells of approximately 2,500 square kilometers each.

Plant species distribution ranges

Plant species distribution records are derived from the currently most comprehensive dataset on continental Africa, the Biogeographic Information System on African Plant Diversity (BISAP), established by the contribution of numerous experts and scientific institutions, and managed by the BIOMAPS working group at the Nees Institute. It comprises data of 16,448 species in 2,796 genera, represented by 354,288 records with varying precisions of locality information. The data originate from herbarium specimen, taxonomic revisions and digitized distribution maps. Species with very few collection localities (less than 5 data entries) and a spatial resolution of more than 0.5 degrees were excluded from the following analysis, resulting in 3,144 species and more than 70,000 individual data points (for further details see Küper et al., 2006; Sommer, 2008). Potential distribution ranges for all 3,144 individual species were derived from analyses conducted by Sommer (2008) at the Nees Institute for Biodiversity of Plants, University of Bonn. In this study, geographical distribution ranges were modelled using an environmental niche modelling approach (MaxEnt, Phillips et al., 2006). Five meaningful variables were used as environmental parameters: one is a proxy for topographic complexity, two are related to energy/temperature, and two refer to water availability, provided by the Tyndall Center for Climate Change Research (Mitchell et al., 2004). The dataset comprises climate data at 0.5 degree resolution for a reference dataset (1960-1990) as well as for five different general circulation models. This study focuses on the HadCM3 model, with a dataset from the year 2000.

Species richness was calculated by superimposing all modelled geographic ranges of 3,144 plant species across continental Africa (Figure 5.1). For further calculations, species distribution ranges were used individually.

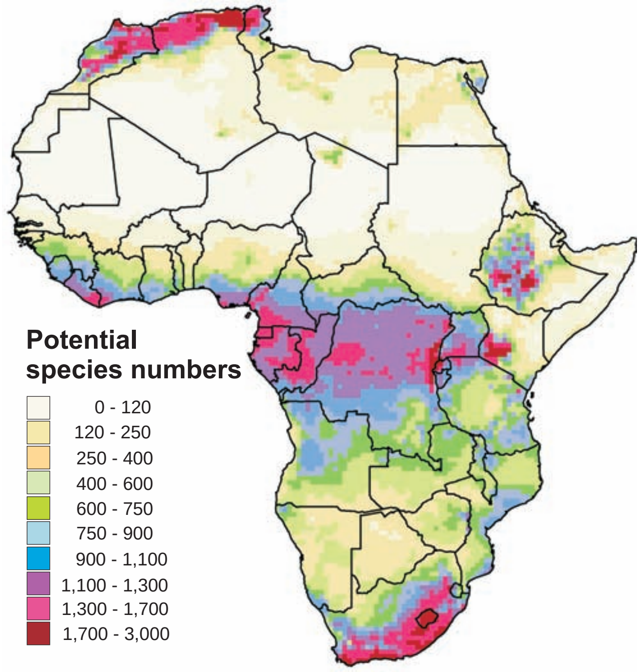


Figure 5.1: Contemporary potential plant species numbers based on distribution records and superimposed modelled geographic ranges of 3,144 plant species across continental Africa derived from Sommer (2008).

LandShift – A dynamic land use model

Current patterns and future scenarios of land use were derived from the spatially explicit dynamic land use model *LandShift* (Schaldach et al., 2006). The data are provided by the Center for Environmental Systems Research (CESR) headed by Prof. Dr. Joseph Alcamo and coordinated by Dr. Rüdiger Schaldach of the GRID-Land working group at the University of Kassel.

LandShift (**Land** **S**imulation to **H**armonize and **I**ntegrate **F**reshwater availability and the **T**errestrial environment) aims at simulating and analyzing land use dynamics and related impacts on the environment at continental and global scales.

LandShift has a modular structure that allows the integration of various functional model components, including socio-economic drivers, native vegetation, agriculture and grassland, water system, climate change, environmental impacts as well as effects on hydrological and bio-geochemical processes. The model works first on a country level (macro-level), for which exogenous model drivers are specified, including demands for agricultural commodities and others such as urban areas. These demands were regionalized to a grid with a spatial resolution of approximately 10 square kilometers (micro-level) by the LandShift module, including landscape (soil, slope, river network), land use (type, population density, protected areas), yield maps, and biomass production. The model provides outputs for time steps of 5 years from 2000 until 2050. The following land use types are classified and modelled: rangeland such as pasture, and cropland such as maize, soybeans, or rice, further urban and barren land. Native habitats such as forest type, shrublands, savanna and grassland are differentiated. Future simulations are based on socio-economic scenarios of the GEO-4 assessment (Global Environmental Outlook UNEP, 2007a):

(1) The "Markets First" scenario assumes that current values and expectations of the developed world prevail, market forces dominate an economic globalization and liberalization. The result is that the environmental standards decline, pressure on resources remains high, poverty and environmental degradation become particularly severe in the developing world (UNEP, 2007a).

(2) The "Sustainability First" scenario assumes a new environment and development paradigm, a support for sustainable policy measures and accountable corporate behavior, collaboration among governments, stakeholder groups, indigenous peoples and individual citizens. Results are improvements in all areas. Because of the time required to achieve necessary cooperation the rate of change would be slow. But continuing, long-term improvements in environmental measures were potentially high (UNEP, 2007a). Further scenarios are described in detail in Chapter 1.5.

The following analyses are based on the "Markets First" scenario, because the storyline of this scenario with its strong focus on market forces and economic globalization appears to be the most meaningful for species persistence: the decline of conservation priorities and continuing demand on natural resources.

Data compilation

Our analysis combines datasets of species geographical distribution ranges and land use data of the available data:

- Potential distribution ranges were available at a spatial resolution of 0.5 degrees.
- Land use data were available at a spatial resolution of 0.1 degrees from 2000 to 2050.

We focused on the years 2000 and 2050 using one single land use type that incorporates all types of land use (Figure 5.2). Land use data were rescaled to a spatial resolution of 0.5 degrees to match the species distribution data. In order to maintain the maximum amount of land use information, the proportion of land use per 0.5 degrees grid cell was calculated (36 land use pixels according to 0.1 degrees resolution, with approximately 50 × 50 kilometers cell size).

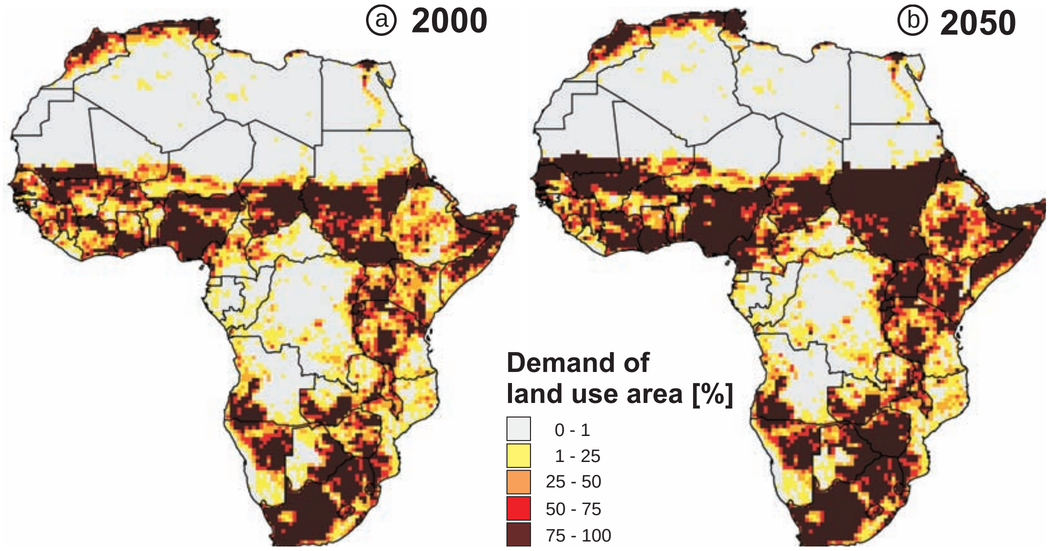


Figure 5.2: Land use demand (including cropland, rangeland, pasture and urban areas) as percentage of total land area per grid cell at a spatial resolution of 0.5 degrees for the year 2000 (a) and 2050 (b) referring to the dynamic land use model *LandShift* using the GEO-4 "Markets First" scenario (Schaldach et al., 2006).

Impact of land use on suitable habitats

The impact of land use on suitable plant habitats was identified for the years 2000 and 2050. Therefore, potential suitable habitats of each individual plant species (binary presences of each species) were intersected with modelled current and future land use patterns (proportion per 50 × 50 kilometers grid cell). In this procedure, the proportion of land use area per cell was subtracted from the potential habitat to obtain the converted habitat per cell (Figure 5.3). All converted habitats were summed to obtain the entire size of the converted distribution range per species. The converted distribution range reflects the entire land use area inside the potential distribution of a respective species. This is expressed by equation 5.1 for each grid cell (i):

$$A_c = A_p - \sum_{i=1}^{n} (1 - A_l), \tag{5.1}$$

with

A_c = converted distribution range (in grid cells),
A_p = potential distribution range (in grid cells),
A_l = proportion of land use per grid cell (0 – 1), and
n = number of grid cells per species.

This procedure was performed for all 3,144 species and for the years 2000 and 2050.

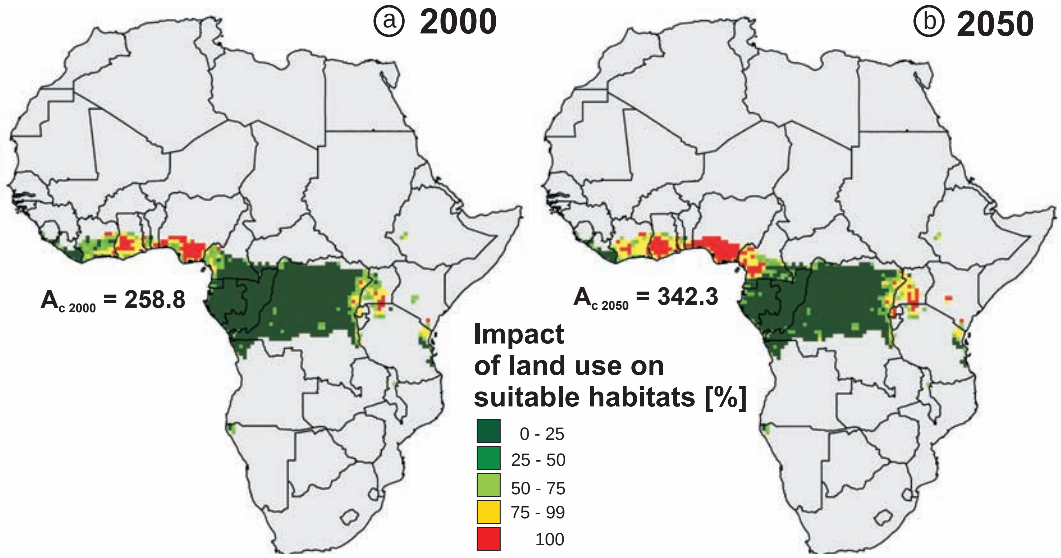


Figure 5.3: Converted potential suitable habitats of *Cussonia bancoensis* in 2000 ($A_{c2000} = 258.8$) and converted habitats in 2050 ($A_{c2050} = 342.3$) as an example referring to the potential distribution range ($A_p = 1114$). Graduated green to red describes the conversion of range size due to land use intensities. Land use data are derived from the dynamic land use model *LandShift* using the GEO–4 "Markets First" scenario (Schaldach et al., 2006).

The converted distribution range A_c is calculated by substracting the sum of the remaining area $(1 - A_l)$ per grid cell n from the potential distribution range A_p. The percentages of unconverted range size per species were calculated and visualized in scatterplots with marginal histograms. The ten percent of species (315 species) defined by the most converted areas, were identified for the years 2000 and 2050. For both time steps, the potential ranges of these species were superimposed. Generated maps were used to identify the change of species with the most converted areas and where they are potentially distributed.

5.3 Results

Conversion of potential species ranges

Potential range sizes of all species are approximately log-normal distributed, the mean range size accounts for 1,596 grid cells with approximately 3.9 million km^2 (Table 5.1). Land use changes, referring to the land use model *LandShift*, causes an increase of intensively used areas for agriculture, rangeland and pasture from about 32% in 2000 to 40% in 2050 across the African continent.

The combination of potential range maps with current and future land use patterns results in estimations of proportional habitat conversion per species. Species range

Table 5.1: Potential range size and habitat conversion were analyzed across continental Africa. The minimum, maximum, and mean of potential range size (without any impact of land use) and of habitat conversion were calculated in grid cells and percentage for the year 2000 and 2050.

	Species range size (in grid cells)			**Habitat conversion (percentage)**		
	Min.	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**
Potential	5	10,184	1,596	-	-	-
Year 2000	3.3	7,025	1,047	0%	78%	37%
Year 2050	3.2	6,323	930	0%	81%	44%

conversions (compared to estimates without land use information) are projected to increase from 37% in 2000 to 44% in 2050 across continental Africa (Table 5.1). No species range is estimated to be converted by 100% of the potential habitat, the maximum conversion is 78% in 2000 and 82% in 2050.

Potential range size versus habitat conversion (in %) of the year 2000 indicates a less percentage in conversion of potentially suitable habitats compared to the year 2050 (Figure 5.4). The mean range conversion is greatest for species having small range sizes. The lowest range size conversions relate to small range sizes. Species will be significantly more affected by habitat conversion in 2050 tested by Wilcoxon signed rank with a p-value $< 2.2e\text{-}16$.

Habitat conversion (in %) versus potential range size in the year 2000 indicates an increase of species frequency that habitat may be converted, with a mean in c. 40%, and a maximal conversion of 80% (Figure 5.4). An increase of species frequency for the year 2050 indicates that habitat may be converted with a mean of c. 50%, and a maximal conversion of 90%. It is shown that habitats of more wide ranging species may be affected in comparison to both time steps.

Conversion of current and future species ranges

The relationship between estimated potential range size versus the habitat conversion of each species due to current and future land use is demonstrated by scatterplots with two marginal histograms (Figure 5.5). Converted range sizes are approximately log-normal distributed. In the two histograms the densities of species frequencies per range size and habitat conversion category are plotted. Most species have small ranges (Figure 5.5, upper histogram). The histograms located between the scatterplots indicate that habitat conversion increases in all categories, especially in the higher ones. Species with large ranges are projected to have mean proportions of conversion (Figure 5.5, central

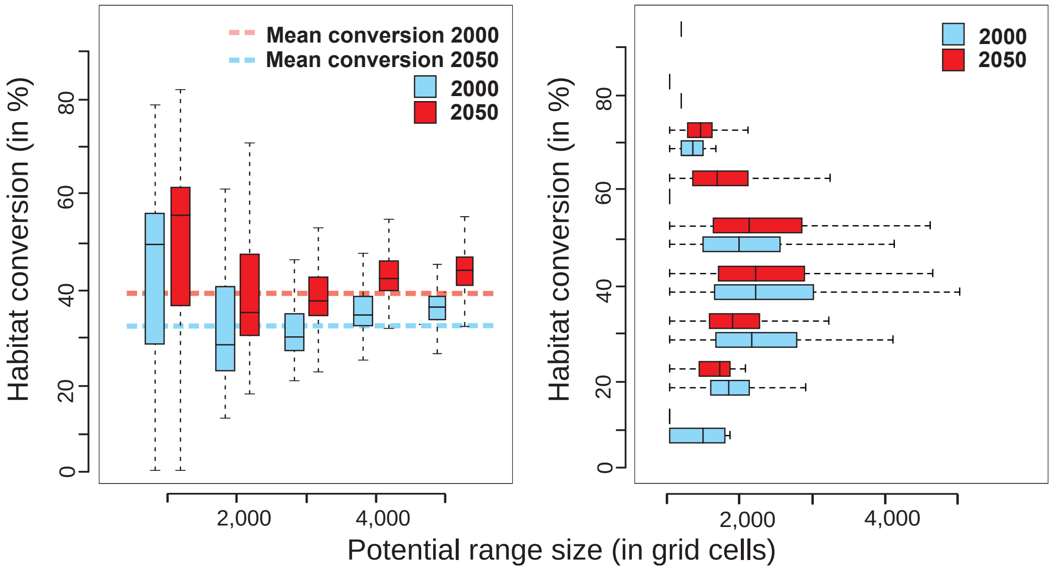


Figure 5.4: Box-whiskerplots of the potential range size (in grid cells) versus habitat conversion (in %) estimated for the year 2000 and 2050 (left figure). Box-whiskerplots of the habitat conversion (in %) versus potential range size (in grid cells) estimated for the year 2000 and 2050 (right figure).

histogram). Habitat conversion increases between the years and may affect different species. The ten percent of species defined by the most converted habitats, are marked in red color (Figure 5.5). The composition of these ten percent of species is projected to change by 25% (77 species).

Mapping most threatened species - currently and in future

A considerable change of species composition is projected from 2000 to 2050 (Figure 5.5). The following analyses consider species that belong to the ten percent of species having the most converted habitats within their distribution range. Potential distribution ranges of the ten percent of species (315) having the most converted habitats were superimposed (Figures 5.6). This allows to identify those areas across continental Africa, where most potentially threatened species are located. The most threatened species are mainly range-restricted, by high percentage of converted habitats by land use activities. In the year 2000, these areas are mainly located in South Africa, the Albertine Rift, Central Angola and the Ethiopian highlands (Figure 5.6 (a)). Threatened species may additionally be located in the savanna regions of sub-Saharan Africa (Figure 5.6 (b)). Species predominantly occurring in savanna regions are those having larger range sizes (Figure 5.7).

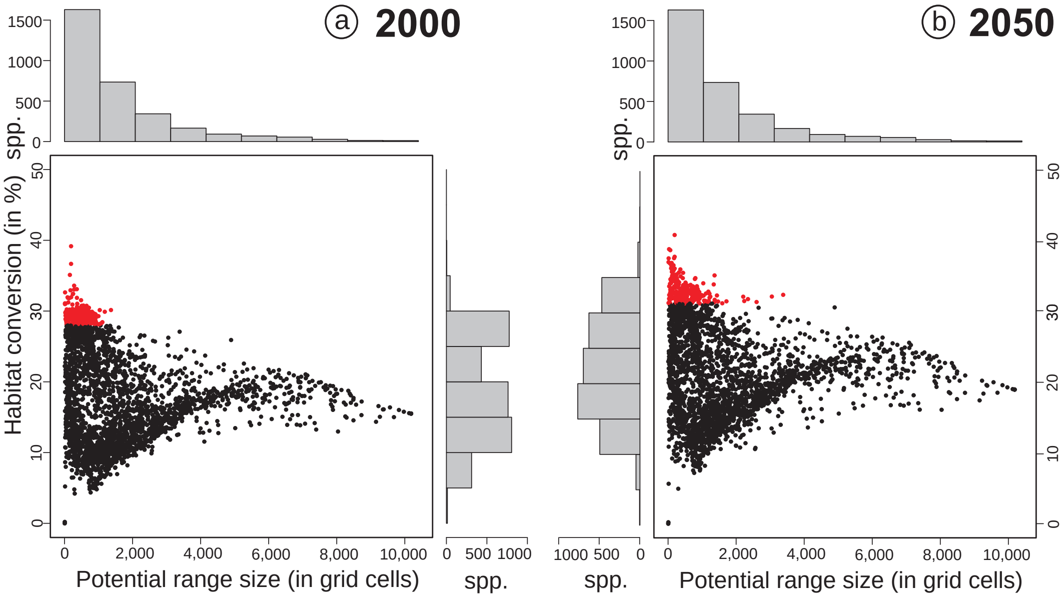


Figure 5.5: Scatterplots symbolize the relationship between potential range size and the proportion of converted habitat due to land use in 2000 (a) and 2050 (b). Range sizes of the ten percent of species defined by the most converted habitats are red marked. The histograms plot the density of species frequencies per each range category.

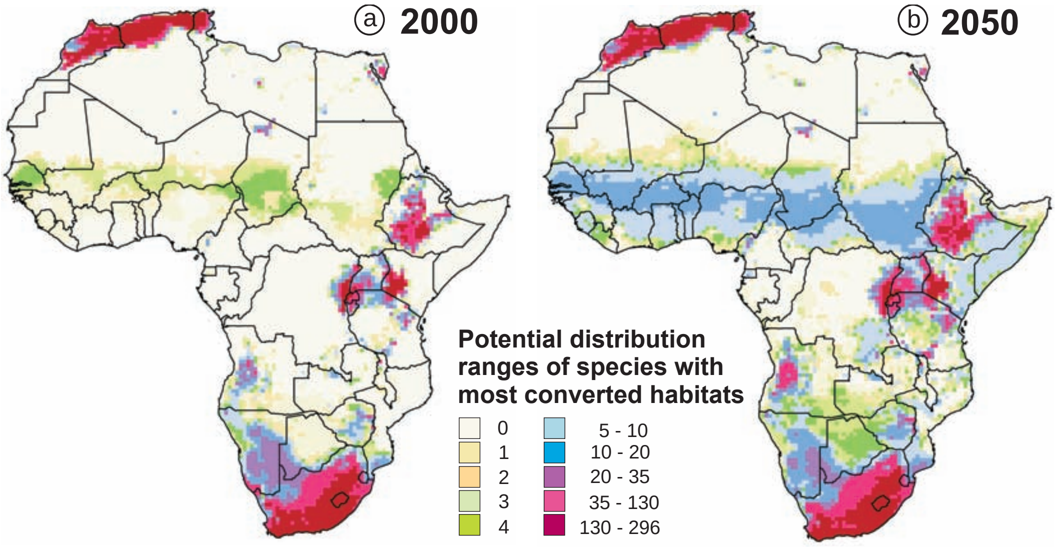


Figure 5.6: Potential species numbers of the 10 percent of species, that contain most converted habitats within their distribution range (315) of the year 2000 (a) and 2050 (b) according to the land use scenario "Markets First". The analyses were performed at a spatial resolution of 0.5 degrees.

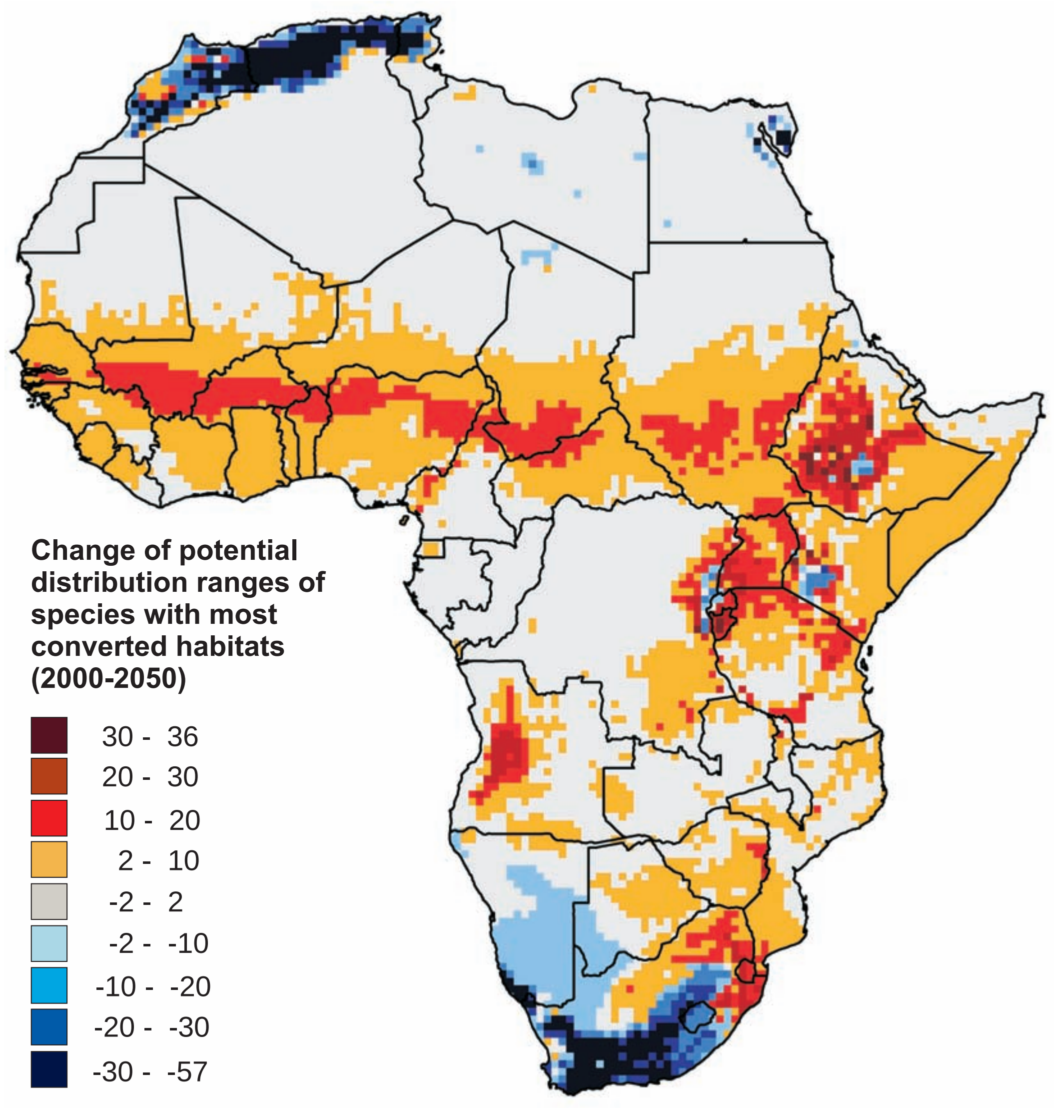


Figure 5.7: Change between 2000 and 2050 of potential species numbers of the ten percent of species (315) that contain the most converted habitats due to land use change. Red colors indicate an decrease and blue colors an increase of the number of threatened species. The analyses were performed at a spatial resolution of 0.5 degrees.

5.4 Discussion

The presented results show estimations of current and future land use threats on individual plant species distribution ranges across continental Africa. The main determinant is land use and the associated habitat conversion, fragmentation and destruction.

According to our approach, ranges overlapping with high land use activities are more converted than species having ranges falling entirely in undisturbed areas. These estimations depend heavily on the accuracy of land use predictions. In the future, the demand of food and energy is projected to increase, resulting in a growing pressure on land area. Agricultural areas may expand into regions not used today and less suitable for cultivation and livestock breeding. These may mostly be dry savanna regions, dominated by a vegetation of wide ranging species. Our results indicate that these regions hold species that may fall under the ten percent of species which are defined by the most converted habitats.

Referring to the results of this study, no species may lose its entire range, thus, they are not threatened by habitat conversion of land use in 100% of their potential area. The loss of suitable habitats does not indicate a definite extinction risk, because many other factors are important for species persistence. Rather we anticipate that current and future land use changes will cause a species loss that may occur gradually over time. However, the point of extinction can not be defined by the size of the remaining range.

The largest potential proportional conversion of range size occurs among species that have restricted ranges. This highlights that species with small distribution ranges are exposed to either a very high risk of extinction or a very low risk, depending on whether their ranges are located within regions with high or low land use activities. This leads to the conclusion that range restricted species are not necessarily endangered. However, those restricted species that do not appear threatened referring to our analyses, may still be at great threat as any incidental loss in habitat area will capture a large proportion of their ranges.

In contrast, wide-ranging species are less affected by high proportional rates of habitat conversion, confirming that large ranges provide a buffer against land use changes. The study indicates that the range of many wide-ranging species is subdivided into small isolated fragments, which leads to a disturbance of species interactions within and between un-transformed patches. Wide-ranging species may be more sensitive to habitat conversion, fragmentation and destruction, that will definitely increase the pressure on species habitats. These effects are not incorporated in our study.

A precondition for precise results is the adequate quality of input data. We used plant distribution datasets and land use information that contain, the recently most comprehensive and complete data of continental Africa. However, deficits remain and have to be critically discussed. First, the geographical distribution ranges of plants are necessarily overestimated, due to the statistical modelling approach, as it focuses on macro-environmental rather than micro-environmental factors, and pays no explicit attention to species interactions. Due to this, high species numbers in the Atlas-region in Morocco occur because of similar climatic/environmental variables as in the South-African diversity centers. Further, the influence of sampling bias is exemplarily apparent in Angola and the Congo Basin. Both are predicted to have higher species numbers than values indicated by the documented occurrences. Both are under-collected - Angola because of political instability, and the Congo Basin because of inaccessibility for field work (Lawton et al., 1998; Taplin and Lovett, 2003). Range maps are a scale dependent abstraction of a species' actual occurrence that limit the interpretation at fine geographic scales. To refine estimates of plant extinction rates, it will be necessary to improve the quality, quantity and availability of collection data.

Land use data had been estimated by the dynamic land use model *LandShift*. In respect to socio-economic factors of each African country, the model calculates land use patterns in regard to suitable environmental conditions and demand for food and energy. This leads to possible and plausible land use patterns for different future scenarios until 2050. These patterns can be treated as the possible demand of agricultural area and should not be seen as a current realistic image of the Earth's surface and forecast of future land cover.

We did not consider effects of future climate change in our analysis. Climate change will threaten many African plant species through a variety of mechanisms, including shifts of climatically suitable habitats (Thomas et al., 2004; Sommer et al., accepted). The ability of species to respond to changing climate conditions will be diminished by land use, as migration corridors may be cut. Increasing numbers of species would be threatened by climate change additionally to land use change. Also, we did not include other possible causes of range conversion such as synergistic human disturbances (e.g. fire, logging, harvesting), or disruptions of biological interactions such as pollination (Feeley and Silman, 2009). The distorted biological interactions may be even stronger drivers of species loss from disturbed forests than the direct effects of habitat change (Terborgh et al., 2006; Feeley and Terborgh, 2008; Feeley and Silman, 2009). Also it is likely that the extinction risk will differ between species, especially as estimates were based only on predicted changes in range size and did not incorporate any physiological or ecological responses to disturbance. Adding up all these drivers which we did not include in our approach, the numbers of endangered and threatened species, and those already predicted to extinct, would be even higher.

By estimating changes of species ranges, we only considered the loss of native habitats and did not allow for benefits such as any successional regrowth or habitat recovery. If agro-ecosystems are able to support species that would otherwise be threatened, loss of habitats will be slowed and extinction risks decreased (Wright et al., 2006; Perfecto et al., 2009).

Assuming that there is no difference in the responses of species to different land use practices, this approach yields reliable and urgently needed insights into the impact and interrelationships of the major threat to species diversity at continental scale.

5.5 Conclusions

An understanding of various and complex responses of species to human disturbances is urgently needed to define effective conservation strategies. An important step towards this goal is to quantify continent-wide the impact of land use on plant habitats, as land use is assumed to be the main driver of biodiversity loss on the macro-scale. Using the assumption that land use is the main driver of plant habitat loss, we estimate high rates of range conversion. This does not definitely enforce species extinction, rather it results in a reduction of the size of suitable habitats of species. Already today, suitable habitats may be dramatically constricted, due to human developments in respect to land use activities. In future, an increasing number of species habitats may be threatened that are currently not in danger. In our analyses, we predict that 44% (as an average) of habitats of the more than 3,144 examined African vascular plant species considered will be lost, fragmented and converted by 2050 due to land use dynamics. It is therefore urgently necessary to consider possible future threats of land use for the evaluation of the species' threat status. Un-transformed habitats may still be disastrously affected by climate change or other drivers that effect habitat conversion. In respect to estimated future threats the high conversion rate of native habitats calls for strong and immediate action by precising conservation priorities. Assuming that there is no difference in the responses of species and ecosystem to different land use depending on land use practices, this approach yields reliable insights into the impact of land use on species diversity at a continental scale.

CHAPTER 6

Quantifying the impact of land use and climate change on African plant diversity

The only way to predict the future is to have power to shape the future.

Eric Hoffer, 1963

Abstract. Land use and climate change are responsible for considerable shifts in size and distribution of species geographic ranges. Accordingly, the reduction of the potential range of a particular species leads to an increase of the relative importance of its remaining range. The range-size rarity index reflects the sum of the inverse range size of all species occurring within a particular area. We considered shifts in range size rarity for 3,144 plant species due to either land use or climate change and for both in combination for continental Africa. Today, areas housing a large proportion of overall species ranges are located in lowland rainforests and the Afrotropical mountains. Due to the combined effect of land use and climate change, the contribution of many lowland areas the overall species ranges decreases pronouncedly. In contrast, the relative importance of Afromontane areas, the Angolan escarpment, and the Namibian coast to represent overall species ranges increases. The approach facilitates a better measure of the conservation value of particular areas in respect to the future impact of land use and climate change. Thus, the presented results contribute to refine priority areas for conservation, and serve as a valuable indicator to improve nature conservation and management policy.

6.1 Introduction

The conversion of natural habitats by land use and the accelerating effects of climate change are the largest global threats to biodiversity (Chapin et al., 2000; McLaughlin et al., 2002; Higgins, 2007; Jetz et al., 2007). In recent decades, the combined impacts of land use and climate change on species habitats have led to substantial range contractions and species extinctions (Pimm, 2000; Warren et al., 2001; Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003). They are projected to be the main drivers of future biodiversity loss (Sala et al., 2000; Carpenter and Cappuccino, 2005; van Vuuren et al., 2006). Especially African ecosystems are at severe risk of habitat loss and transformation (Lovett et al., 2000; Laurance and Luizao, 2007).

Human population is expected to further increase in the upcoming decades (UNEP, 2007b) substantially putting pressure on undisturbed areas due to growing demands for food and energy (MEA, 2005). Land use changes will lead to an expansion of agricultural used areas, which is expected to remain the dominant driver of biodiversity loss (Sala et al., 2000; MEA, 2005; van Vuuren et al., 2006). The most extensive changes may occur in sub-Saharan savannas, in the Capensis and the Afrotropical mountains (Alcamo et al., 2005; MEA, 2005; Schaldach et al., 2006). These regions are among the major remaining areas having potential for an expansion of agricultural areas. Further, climate change-induced decreases in yield will provoke this expansion.

Future climate scenarios indicate a possible temperature rise in Africa by several degrees within the next century, and changes in the amount and seasonality of rainfall with impact for local ecosystems (Broennimann et al., 2006; Thuiller et al., 2006; van Vuuren et al., 2006). This imposes a major additional threat on biodiversity, causing extinction of species (Hughes, 2000; McCarty, 2001; Parmesan and Yohe, 2003; Root et al., 2003). Macroecological studies have shown that climate change may lead to a shift and reduction of distribution ranges of plant species (Svenning and Skov, 2004; Thuiller et al., 2005a; Jetz et al., 2007; Luoto et al., 2006). Further, shifts of species distribution due to climate change will be imposed by migratory barriers build through land use activities (Higgins, 2007).

The major challenges in the conservation of species are the identification and preservation of intact habitats with regard to future threats such as land use and climate change. A key issue is the understanding of how future climate and land use changes affect geographical spatial distribution of species and the value of a particular areas.

The spatial distribution of all taxa is confined to specific areas, the range sizes, and taxa are termed endemics for these areas (Kier and Barthlott, 2001). Endemism is defined as the uniqueness of a species to a particular geographic location such as a specific island, habitat type or continent (Orme et al., 2005). Endemism can also be viewed as a form of range-size rarity (Rabinowitz, 1981), and in the present study it is treated in this sense. The index of range-size rarity (*rsr*) is commonly regarded as an important criterion for the biological value of a particular area that includes a weight for each species (Kier and Barthlott, 2001). One of the key features of the *rsr* index is the calculation by the inverse of the range size of all species occurring within the considered area. This effects a higher value for range restricted species and a lower value for widespread species. The rsr is the sum of all individual species recorded per area, and describes the relative importance of a particular area (Lovett et al., 2000; Lennon et al., 2004). We propose to adjust the existing index of range-size rarity (Williams, 1993) that facilitates to quantify the impact of land use and climate change on plant species patterns by the consideration of the reduction of range size of individual species.

The objective of this study is (1) to explore and (2) to locate the quantitative impact of land use and climate change on plant diversity in Africa. Plant diversity is analyzed in respect to the *rsr* per area under changing environmental conditions. For that purpose, we used the dynamic land use model LandShift (Schaldach et al., 2006; Schaldach and Koch, 2009) to quantify future land use change under two different scenarios (derived from Global Environmental Assessment 4). Current and future plant species distribution ranges refer to a study performed by Sommer (2008). For this analysis distribution ranges of 3,144 African vascular plant species were modelled, using different future climate scenarios (derived from the IPCC).

This study analyses three aspects referring to the size and distribution of geographic ranges of African plant species in respect to land use and climate change:

– Areas that are occupied by land use and that are getting unsuitable due to climate change were not longer suitable for the respective species.

– The adjusted range-size rarity index compares individual potential and converted distribution ranges per area in respect to continental Africa.

– The examination of both drivers, current and future land use and climate change, in isolation and in combination allows to account for the individual contribution of each driver on range-size rarity.

Our findings highlight the large pressure on Africa’s plant species, and emphasize the need for the development and integration into conservation priorities.

6.2 Methods

Data compilation

Species distribution ranges. Plant species distribution ranges refer to a study performed by Sommer (2008). In this study occurrence information of 3,144 vascular plant species at a spatial resolution of 0.5 degrees was used. Each taxonomically revised species was represented by at least five collection localities. Plant distribution data refer to the Biogeographic Information System on African Plant Diversity (BISAP), established by the contribution of numerous experts and scientific institutions (Küper et al., 2004). Potential ranges of individual species were modelled, using an environmental niche modelling approach (MaxEnt, Phillips et al., 2006). As environmental parameters five ecologically meaningful variables were used: one is a proxy for topographic complexity, two are related to energy/temperature, and two refer to water availability, provided by the Tyndall Center for Climate Change Research (Mitchell et al., 2004).
Sommer (2008) calculated the possible impact of climate change on species distribution. Future climate data refer to the four major families of IPCC greenhouse gas emission scenarios (A1FI, A2, B1, B2, Intergovernmental Panel on Climate Change 2000). The model was performed at time steps of 20 years from 2000 until 2100 for the pessimistic (A1FI) scenario and the conservative (B1) scenario: The A1FI scenario assumes a rapid market - driven growth with convergence in incomes and culture in an unsustainable world. This leads to a fossil - intensive economic growth, with a best estimate of 4.0°C average global surface temperature rise by 2100. The B1 scenario emphasizes global solutions to sustainability featuring a rapid shift to a service orientated economy and clean technologies, and the pursuit of global solutions to economic, social, and environmental problems. This leads to a reduction in material intensity, and a respective best estimate of 1.8°C global warming by 2100. For a detailed description of the dataset, the modelling approach, and a complete acknowledgement of the data contributors see Küper et al. (2004) and Sommer (2008).

Land use patterns. Land use data were derived from the dynamic, spatially explicit land use change model “LandShift” (**Land** **S**imulation to **H**armonize and **I**ntegrate **F**reshwater availability and the **T**errestrial environment), established at the University of Kassel (Schaldach et al., 2006). LandShift has a modular structure that integrates various functional model components, including socio-economic drivers, natural vegetation, agriculture, the water system, climate change, and effects on hydrological and bio-geochemical processes. It allows to estimate the possible demand of area for any production of food and energy, depending on the suitability of land availability. For a detailed description of the model compare Chapter 1.5 and for a technical description of LandShift Schaldach and Koch (2009). For modelling future scenarios, *LandShift* refers to the "Markets First" and the "Sustainable First" scenarios of the GEO-4 assessment (UNEP, 2007b):

Under the conditions of the "Markets First" scenario, crop yields remain lower, imports are limited, and food production is predominantly increased by enlarging the cultivated areas. Grazing pressure on natural vegetation is prominent, and results in higher impacts on the arid and semi-arid ecosystems. Livestock is also increasingly converting natural vegetation. The projected increase in demand for meat will require a substantial increase in livestock raised on planted and fertilized pastures. The expansion of agriculture into marginal areas and overgrazing by livestock, increases the risk of degradation through processes such as soil erosion and nutrient depletion (Hoffman and Ashwell, 2001).

The preference for vegetarian diets under the "Sustainable First" scenario partly explains the smaller fraction of cultivated land, despite the fact that the total regional population is larger (Biggs et al., 2008). The increase of demand will be met by an expansion of the area under cultivation, an increase of the yield on cultivated areas, and the intensification of livestock productivity (Turner, 1990; Biggs and Scholes, 2002). A high pressure and expansion for cultivation of crops, and livestock intensification into marginal areas occurs under both scenarios. These scenarios correspond to the A1FI and the B1 scenario respectively used for modelling future species ranges. Descriptions of the GEO-4 scenarios are described in Chapter 1.5.

Spatial data join. The analyses were performed at a spatial resolution of 0.5 degrees, dividing the study area into 10,864 grid cells of approximately 2,500 square kilometers each. Time lines 2000 (as baseline year), 2020 and 2040 were regarded. Individual potential species distribution ranges were considered using a binary code. The binary code describes if a species is potentially occurring in a grid cell or not. The potential species distribution change with changing climate conditions.

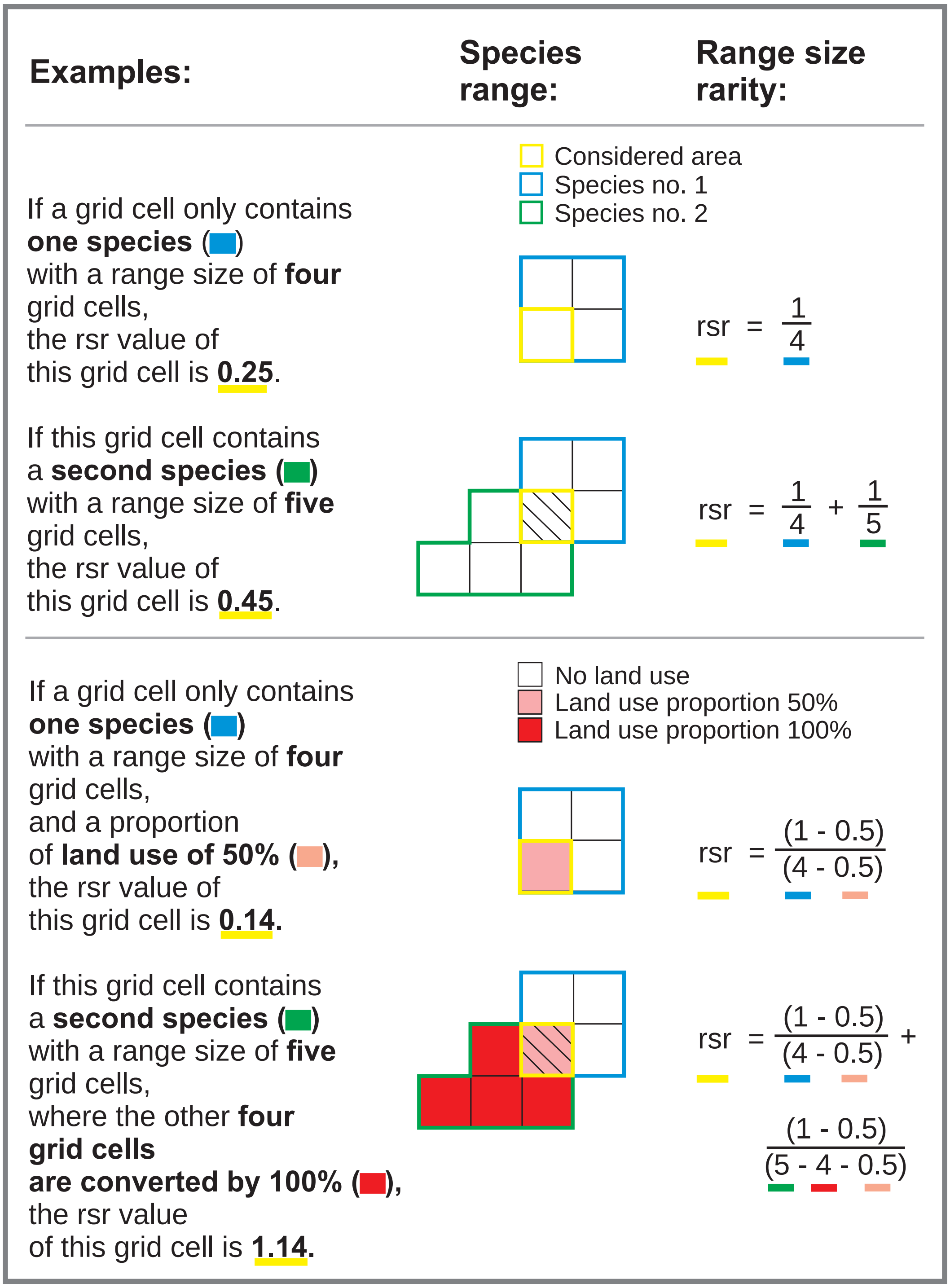
Land use categories (cropland, rangeland, and urban areas) were summarized to a single land use class. These data are available at a spatial resolution of 0.1 degrees. To obtain a resolution that is comparable to the plant information, land use data were rescaled to 0.5 degrees. For that purpose, the continuous proportion of land use per 0.5 degree grid cell was calculated.

Continuous land use information was spatially intersected with binary plant data of each individual species (a total of 3,144 species). Inconsistences among the number of species is due to species that lose their entire suitable habitats due to changing climate conditions. This results in 3,144 single maps for the year 2000 and 3,115 single maps for the year 2020 and 3,104 single maps for the year 2040 (scenario A). For scenario B, this results in 3,144 single maps for the year 2000 and 3,120 single maps for the year 2020 and 3,103 single maps for the year 2040.

Quantifying the impact of land use and climate change

The general assumption is that habitats are converted by land use and climate change. As the absolute impact of land use activities on species ranges is difficult to determine, we assume that the entire area under use is not longer suitable for the persistence of species. Hence, the absolute range size per species is reduced by the proportion of land use per grid cell. Further, climate change may lead to a shift of distribution ranges of plant species, and may lose, or gain suitable habitats. Therefore, we considered climatically unsuitable areas as not longer belonging to the species' range. With a reduction of overall range size the relative importance of the remaining range increases for a species. To quantify the impact of land use and climate change based on the before mentioned assumptions, we used an approach related to the *range-size rarity*-index.

Calculation of range-size rarity. The range-size rarity index (*rsr*) is a criterion for the biological value of a particular area that weights each species by its range size (Williams, 1993; Williams et al., 1996; Kier and Barthlott, 2001). The index refers to a measure of "endemism richness". For the purpose of explaining the principle of the *rsr*-index some terms were defined: Species that are confined to a certain geographical area, are termed endemics for these areas. The *range size* counts for the number of *sampling units* (here: *grid cells*) in which the particular species occurs, we divided Africa into 10,864 *grid cells* of 50 x 50 kilometers each. The key principle of the *rsr*-index is that all species contribute with the inverse of their potential *range size* per *grid cell*. This effects a higher value for range restricted species than for widespread species (Figure 6.1).
Based upon this, the impact of land use and climate change on species *range size* is incorporated. For each considered time step (2000, 2020, 2040) the species *range size* in respect to climate change was recalculated (compare Chapter 6.2: Species distribution ranges). For incorporating the impact of land use on species *range size* the *rsr*-index was adjusted in respect to the proportion of land use inside each species range. For each *grid cell*, only the remaining undisturbed area was considered as suitable for species occurrence (Figure 6.1).



Examples: **Species range:** **Range size rarity:**

☐ Considered area
☐ Species no. 1
☐ Species no. 2

If a grid cell only contains **one species** (🟦) with a range size of **four** grid cells, the rsr value of this grid cell is **0.25**.

$$\mathrm{rsr} = \frac{1}{4}$$

If this grid cell contains a **second species** (🟩) with a range size of **five** grid cells, the rsr value of this grid cell is **0.45**.

$$\mathrm{rsr} = \frac{1}{4} + \frac{1}{5}$$

☐ No land use
▨ Land use proportion 50%
■ Land use proportion 100%

If a grid cell only contains **one species** (🟦) with a range size of **four** grid cells, and a proportion of **land use of 50%** (▨), the rsr value of this grid cell is **0.14.**

$$\mathrm{rsr} = \frac{(1 - 0.5)}{(4 - 0.5)}$$

If this grid cell contains a **second species** (🟩) with a range size of **five** grid cells, where the other **four grid cells are converted by 100%** (🟥), the rsr value of this grid cell is **1.14.**

$$\mathrm{rsr} = \frac{(1 - 0.5)}{(4 - 0.5)} + \frac{(1 - 0.5)}{(5 - 4 - 0.5)}$$

Figure 6.1: Examples for calculating the adjusted range-size rarity index incorporating the effect of land use. The main assumption was that area under use is not suitable for the species occurrence, and hence diminishes the species' range size. The regarded area is framed in yellow. Two species (green and blue frames) with different range sizes and the proportion of land use per area (light red = 50% and dark red = 100%).

The adjusted *rsr* was calculated for each grid cell and 3,144 plant species by the Equation 6.1:

$$rsr = \sum_{i=3144}^{n=1} \frac{(1 - i_g)}{c_n}, \tag{6.1}$$

with

rsr = *rsr* value per grid cell,
i_g = impact-value, the proportion of land use per grid cell, and
c_n = core-area, the potential range size of a species (number of grid cells).

The *rsr* is calculated as the inverse species range c, multiplied with the impact value i_g occurring per grid cell. The model environment regards if a species will completely lose its suitable habitat due to climate change or land use, it not longer contributes to the *rsr*; if a species' range is reduced due to climate change, only the remaining range was considered; and if a species' range increase due to climate change, these areas were additionally considered. For further analyses three aspects were compared:
(1) The individual impact of climate change on plant species ranges.
(2) The individual impact of land use activities on plant species ranges.
(3) The combined impact of land use and climate change on plant species ranges.

Integration of ecological classifications

To interpret our results focusing on ecological manners we used the Biome-classification after Olson et al. (2001) for the entire continent. Biomes are the most basic units to describe global patterns of ecosystem form, process, and biodiversity. They are identified based on general differences in vegetation type associated with regional variations in particular climatic and environmental conditions (Matthews, 1983).
In the following analysis we considered the change of absolute range-size rarity values within biomes. Therefore we chose the largest three biomes in Africa ("Moist broadleaf forests" (1), "Grasslands, savannas and shrublands" (7), "Deserts and shrublands" (13)). Besides representing the largest continuous vegetation units on continental Africa the chosen biomes also provide the most robust data for statistical analysis. For further calculations we considered only species that are supposed to be characteristic for the species composition of a certain African biome. Thus, we selected species that contribute 50% of their entire range to the respective Biome. Those species were analyzed in terms of *rsr* value change in all biomes, in order to investigate which biome could become most important for maintaining a high quality of biodiversity in the future with regard to climate and land use change.

6.3 Results

Current and future range-size rarity

Today, the most important areas in terms of potential range-size rarity (*rsr*) are located in lowland rainforests and the Afrotropical mountains (Figure 6.2 and Figure 6.3). This is due to the particularly high species numbers in lowland rainforests, and the high grade of endemism in Afrotropical mountains.

The potential *rsr* in respect to land use is defined as the actual *rsr*. When the impact of land use is considered, we find that the actual *rsr* generally decreases considerably in the savanna regions that are in high proportions used for land use, and increases in undisturbed regions, respectively. The potential *rsr* patterns across Africa are used as a baseline for all following analyses (Figure 6.2).

In future scenarios the contribution of lowland areas to overall *rsr* decreases pronouncedly, due to either range restrictions by land use or generally unsuitable conditions due to climate change. In contrast, the relative importance of Afromontane areas, the Angolan escarpment, and the Namibian coast to represent overall *rsr* increases.

The sum of species that are considered in the analyses differs per year and scenario. The initial number of 3,144 species decreases according to the respective year and scenario. This depends on the possibility that species completely lose all suitable habitats due to climate change and are not longer considered. Due to land use, no species lose 100% of the potential range.

Results of the “Sustainability First” and “Markets First” future climate and land use scenarios are compared in the following subsection.

Impact of land use and climate change on range-size rarity

Land use exceeds in the relative impact on *rsr* compared to the impact of climate change (“Land use” and “Climate” in Figures 6.4, 6.5). Most visible is that land use leads to a decrease of high proportions of *rsr* in particular areas, accompanied by increases in relative importance of *rsr* in areas not in extensive use. This stands in contrast to the impact of climate change on *rsr* that more generally impacts plant habitats. The combined impact of growing land use activities and climate change on plant species indicates that until 2040 exceeds the impact of both in isolation. The overall *rsr* decreases in lowland regions and increases apparently in a few particular spots of the lowland Rainforest and the Afrotropical mountains (“Combination” in Figure 6.4, 6.5).

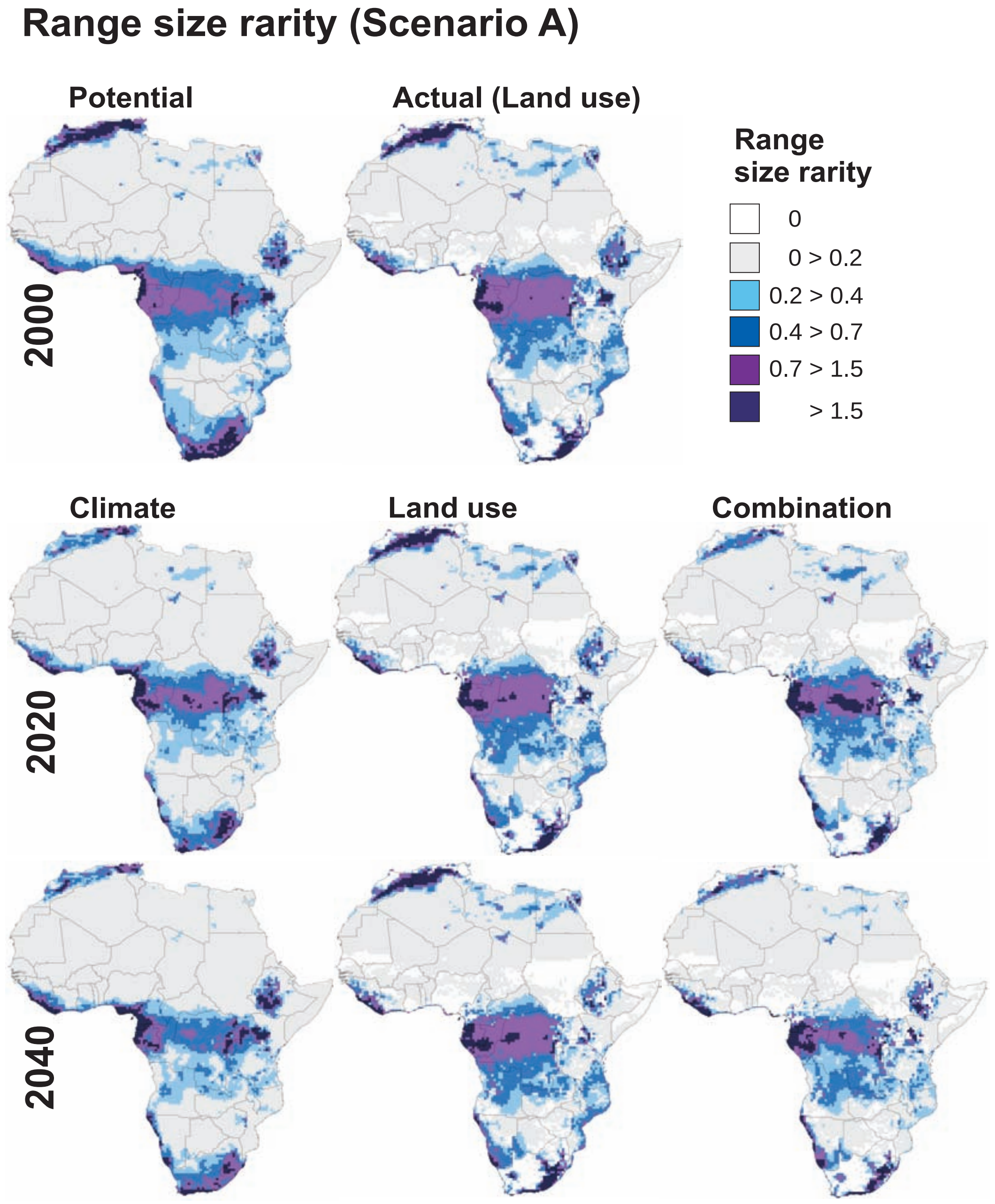


Figure 6.2: Range-size rarity calculated for the baseline year 2000, and the years 2020 and 2040 of the future scenario A ("Markets First"). The isolated impact of climate and land use change are compared to the combined impact of land use and climate change. Analyses were calculated at a spatial resolution of 0.5 degrees.

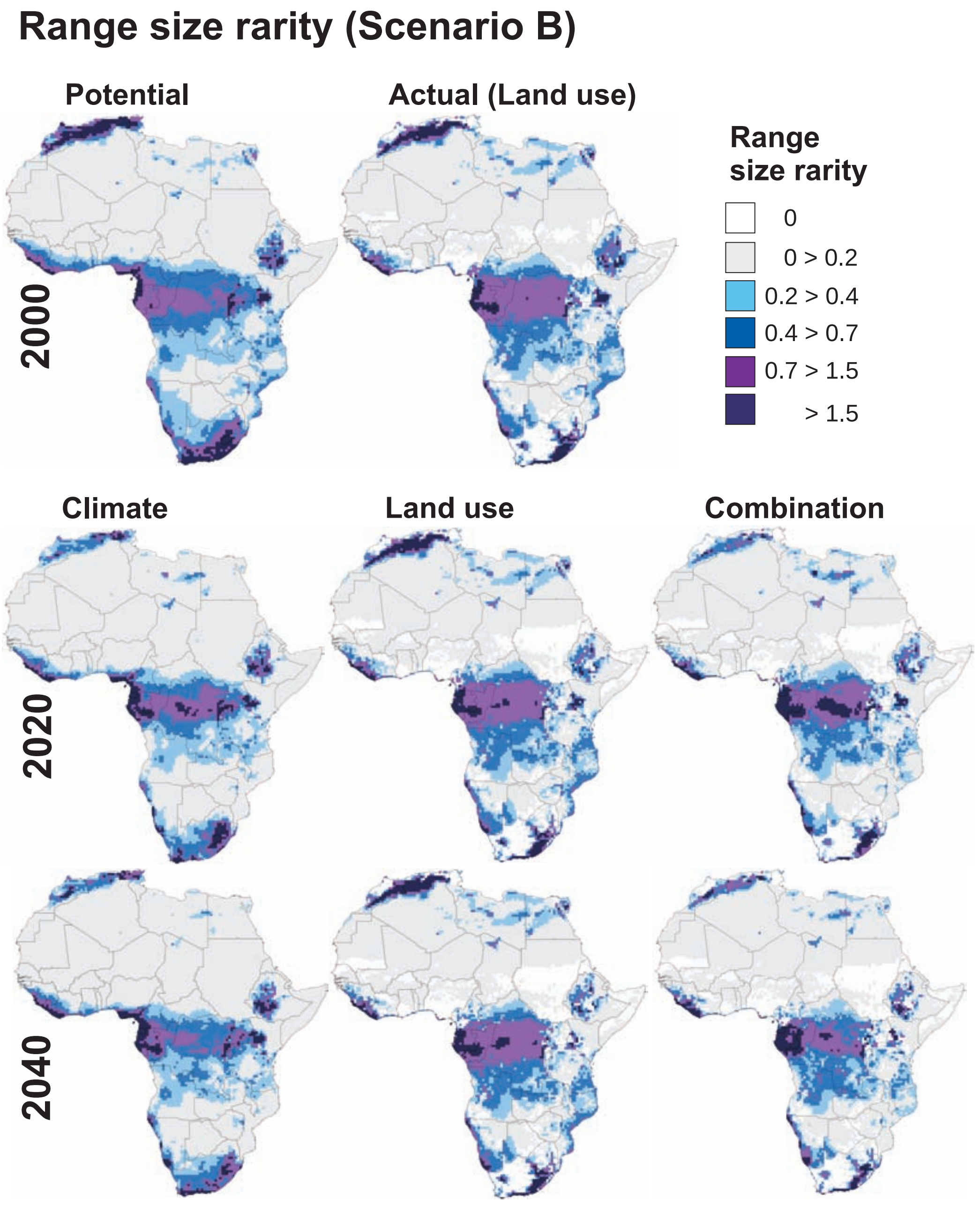


Figure 6.3: Range-size rarity calculated for the baseline year 2000, and the year 2020 and 2040 of the future scenario B ("Sustainability First"). The isolated impact of climate and land use change are compared to the combined impact of land use and climate change. Analyses were calculated at a spatial resolution of 0.5 degrees.

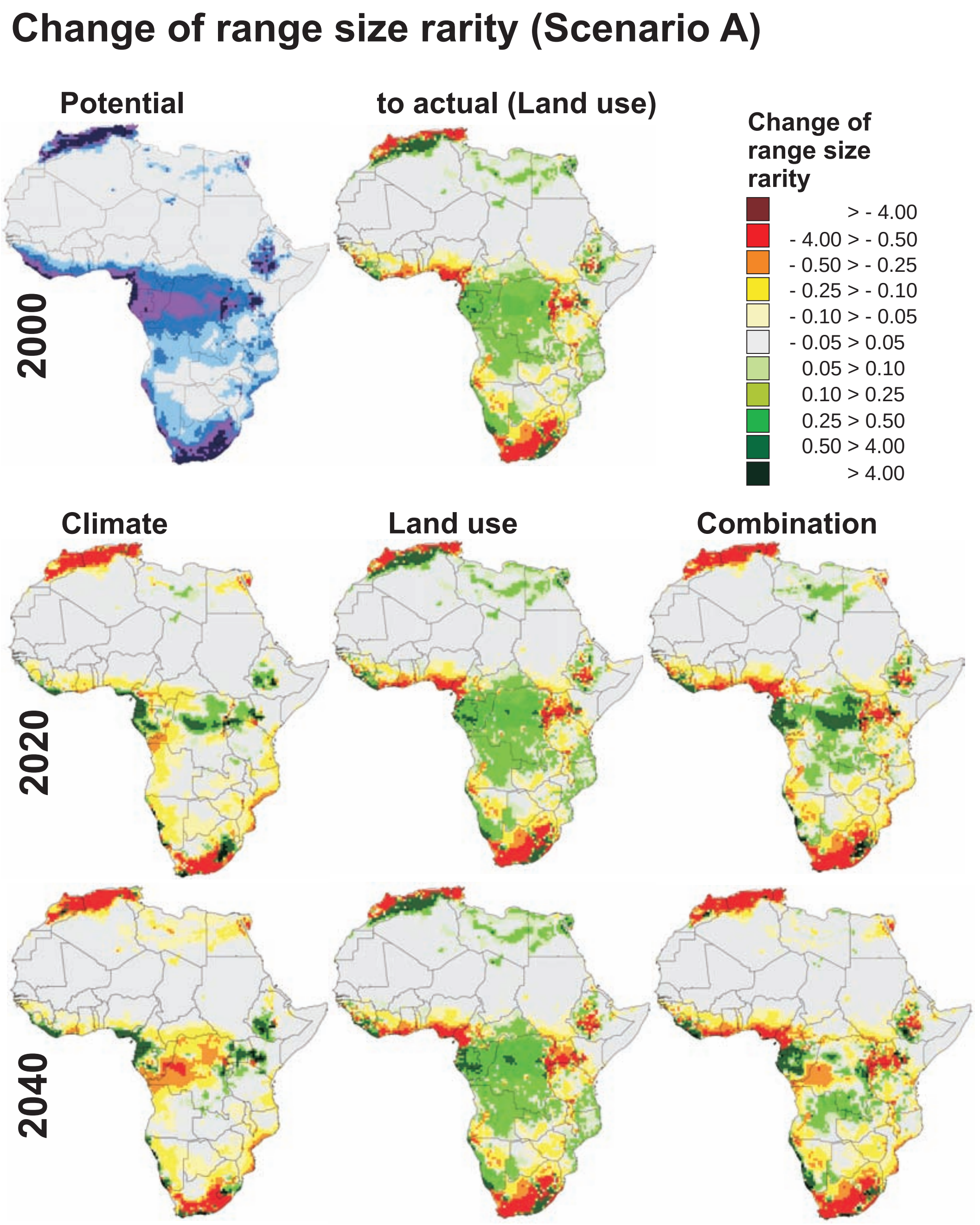


Figure 6.4: The change of the range-size rarity of actual patterns in 2000 and of the years 2020 and 2040 is related to the range-size rarity for the baseline year 2000. Change was calculated as the difference between the potential range-size rarity, the actual, the individual impact of climate change, the individual impact of land use, and the combined impact. Analyses refer to the GEO-4 "Markets First" scenario, and were calculated at a spatial resolution of 0.5 degrees.

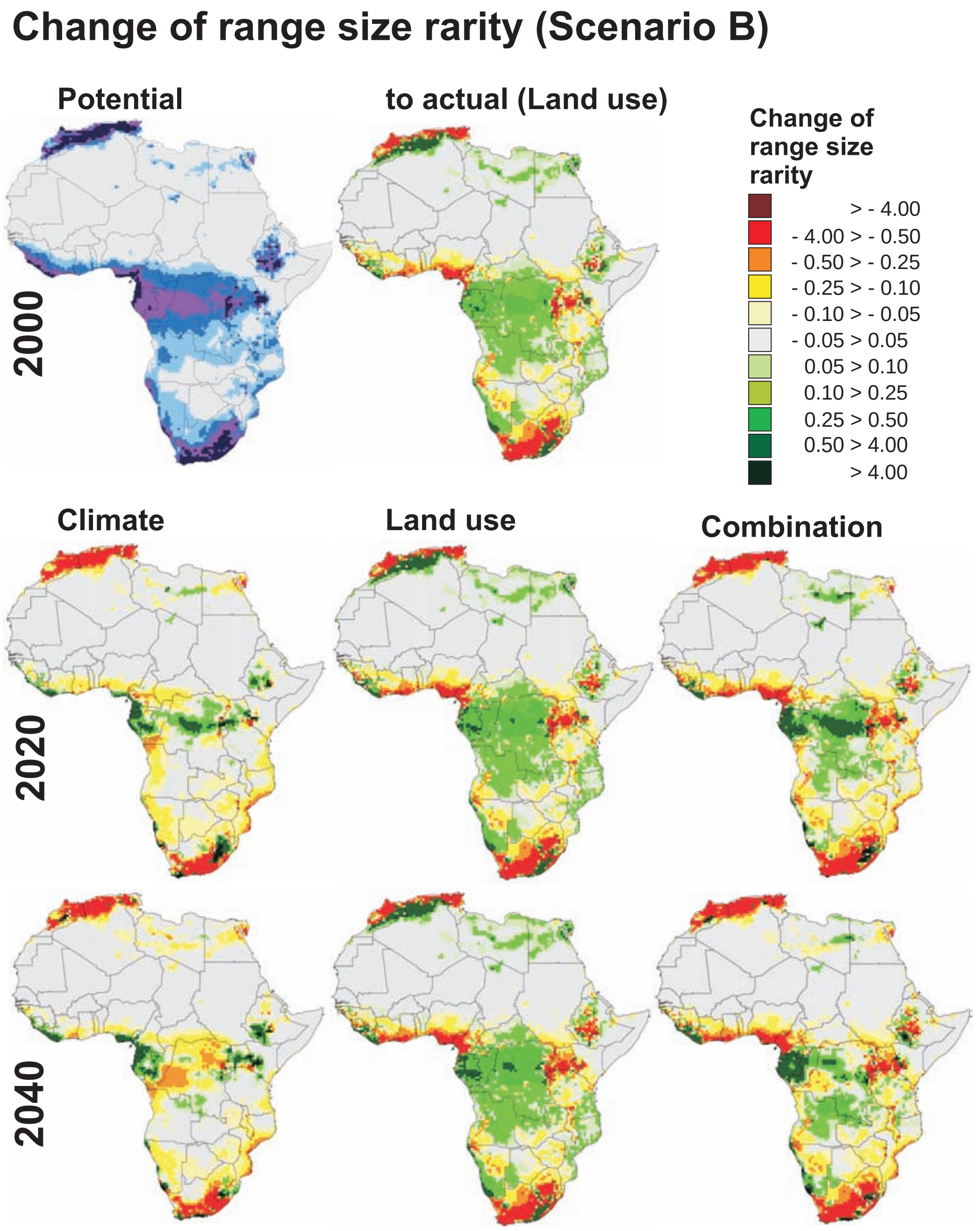


Figure 6.5: The change of the range-size rarity of actual patterns in 2000 and of the years 2020 and 2040 is related to the range-size rarity for the baseline year 2000. Change was calculated as the difference between the potential range-size rarity, the actual, the individual impact of climate change, the individual impact of land use, and the combined impact. Analyses refer to the GEO-4 "Sustainability First" scenario, and were calculated at a spatial resolution of 0.5 degrees.

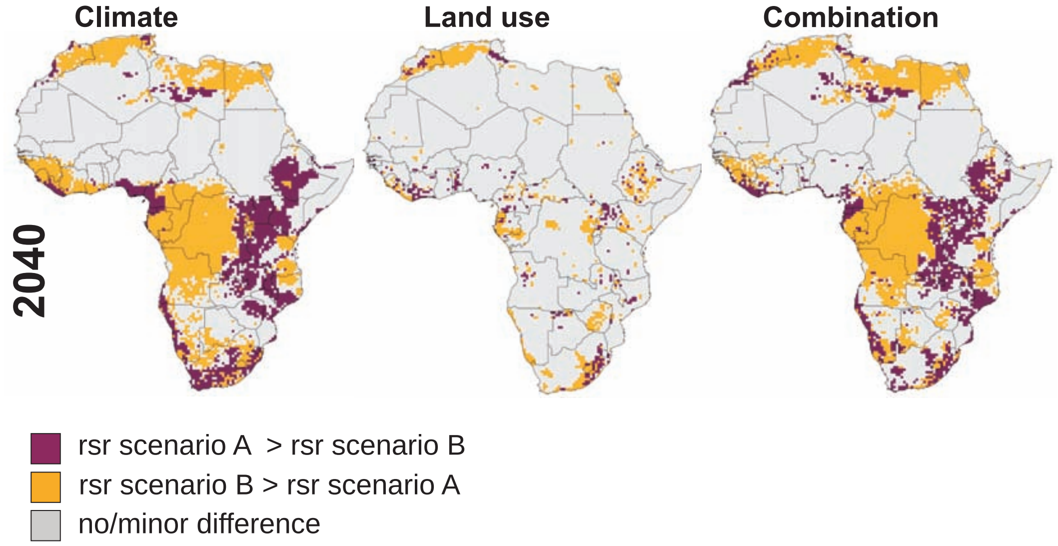


Figure 6.6: Differences in range-size rarity between the two scenarios of future development ("Markets First" and "Sustainability First"). The patterns indicate which scenario has a higher impact of land use and climate change compared individual and in combination. Orange indicate an accelerating impact by the "Markets First", violet an accelerating impact by "Sustainability First", and gray indicate no difference between the scenarios.

Differences of range-size rarity between scenarios

The impact of land use and climate change differs considerably among the two scenarios of future development ("Markets First" and "Sustainability First"). The main reason is that the "Markets First" scenario has a more negative impact on species range sizes as compared to the "Sustainability First" scenario (Figure 6.6), due to a higher land use demand and, most of all, due to the higher estimated temperature rise. A decrease in range size results in considerably higher *rsr* values within the remaining range sizes, whereas there is no longer a contribution of the species to the *rsr* value per grid cell in areas where species do not longer occur. As a consequence, areas maintaining high numbers of particularly range restricted species gain in *rsr* values as compared to areas that lose species occurrences. This effect is exceedingly higher in the "Markets First" scenario, resulting in lower *rsr* values in lowland areas and higher values in the Afrotropical mountains as compared to the "Sustainability First" scenario.

Range-size rarity per biome

Compared to the year 2000, changes in *rsr* per biome to either direction are considerably more pronounced in scenario A than in scenario B (Table 6.1). The strongest increase in *rsr* occurs in the "Moist broadleaf forests" (1). The "Grasslands, savannas

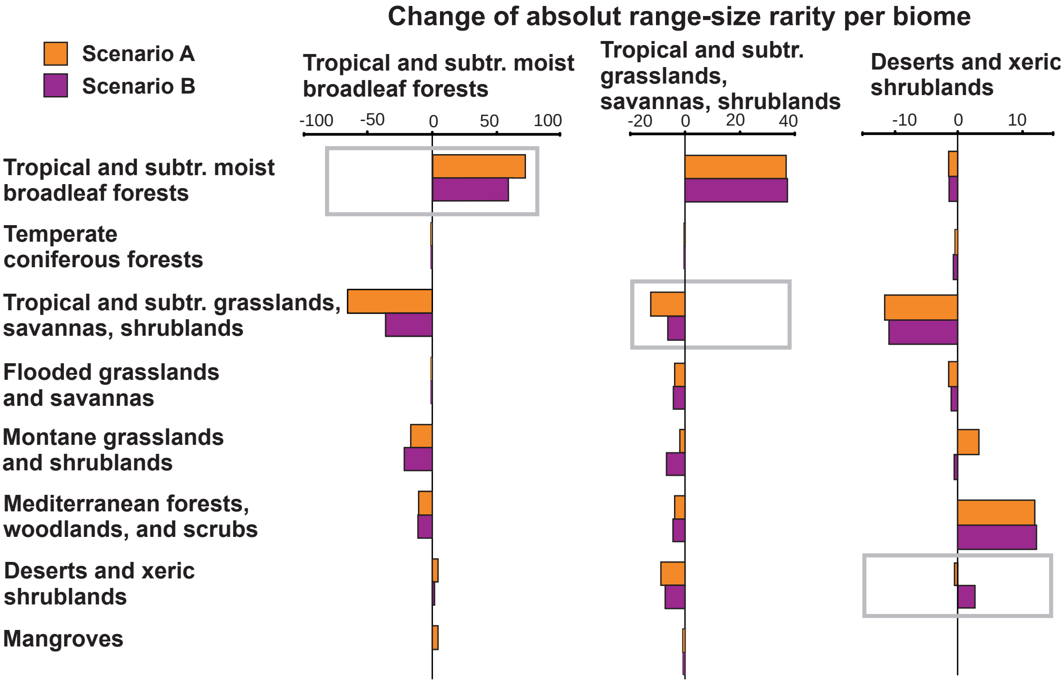


Figure 6.7: Species' contribution of rsr per biome (classification refers to Olson et al. (2001)). Analyzed are species with a range contribution of 50% to the respective biome. Compared are the changes in absolute range-size rarity per respective biome.

and shrublands" (7) decrease in overall *rsr*. Interestingly, the "Deserts and shrublands" (13) increase in *rsr* in scenario A and decrease in the scenario B. However, all areas are facing a pronouncedly high increase in the demand for cropland and livestock farming (Table 6.1), which leads to a decrease of the remaining suitable areas. Analyzed are species with a range contribution of 50% to the respective biome. Compared are the changes in absolute range-size rarity per respective biome. Regarding the pool of species that are dedicated to the three major biomes of Africa, there are noticeable changes of *rsr* among neighboring biomes (Figure 6.7): Most remarkable is the additional contribution of "Tropical and subtropical grasslands, savannas, shrublands" species to the *rsr* of "Tropical and subtropical moist broadleaf forests". As well, the "Tropical and subtropical grasslands, savannas, shrublands" species' contribution to the *rsr* decreases in all other biomes that results in an increase of *rsr* within the "Tropical and subtropical moist broadleaf forests". For "Deserts and shrublands" species is apparent that the species' contribution to *rsr* has only minor changes in the deserts, but higher changes (negative and positive) within all other biomes where species contribute to (Figure 6.8).

Table 6.1: Current and future range-size rarity for the combined future (year 2040) impact per biome (classification refers to Olson et al. (2001)). Compared are the percentages of land use area in 2000 and for the scenarios "Markets First" (Mar.Fir.) and "Sustainability First" (Sust.Fir.) and potential absolute rsr (pot.) and its change for the two scenarios "Markets First" and "Sustainability First" per biome.

		Land use area			**Range-size rarity**		
Biome no.	area (%)	2000 (%)	Mar.Fir. (%)	Sust.Fir. (%)	pot. (*rsr*)	Mar.Fir. (*rsr*)	Sust.Fir. (*rsr*)
01	10.3	22.2	31.4	31.2	894	+239	+223
02	0.1	28.0	29.7	39.1	2	0	0
05	0.1	72.7	81.0	78.8	22	–14	–16
07	46.1	44.9	53.2	53.6	825	–151	–104
09	2.0	44.8	59.2	59.4	21	–9	–9
10	3.1	50.8	62.8	61.0	368	+17	+5
12	3.3	54.3	57.4	55.9	508	–182	–125
13	34.2	10.4	11.0	11.0	461	+70	–63
14	0.2	35.9	53.1	52.7	20	+3	–3
not assigned	0.6	83.8	79.4	84.3	22	–16	–18
all Africa	100	31.4	37.3	34.9	3144	–41	–44

Biome	WWF nomenclature
01	Tropical and subtropical moist broadleaf forests (tropical and subtropical, humid)
02	Tropical and subtropical dry broadleaf forests (tropical and subtropical, semi-humid)
05	Temperate coniferous forests (temperate, humid to semi-humid)
07	Tropical and subtropical grasslands, savannas, and shrublands (tropical and subtropical, semi-arid)
09	Flooded grasslands and savannas (temperate to tropical, fresh or brackish water inundated)
10	Montane grasslands and shrublands (alpine or montane climate)
12	Mediterranean forests, woodlands, and scrub or Sclerophyll forests (temperate warm, semi-humid to semi-arid with winter rainfall)
13	Deserts and xeric shrublands (temperate to tropical, arid)
14	Mangrove (subtropical and tropical, salt water inundated)

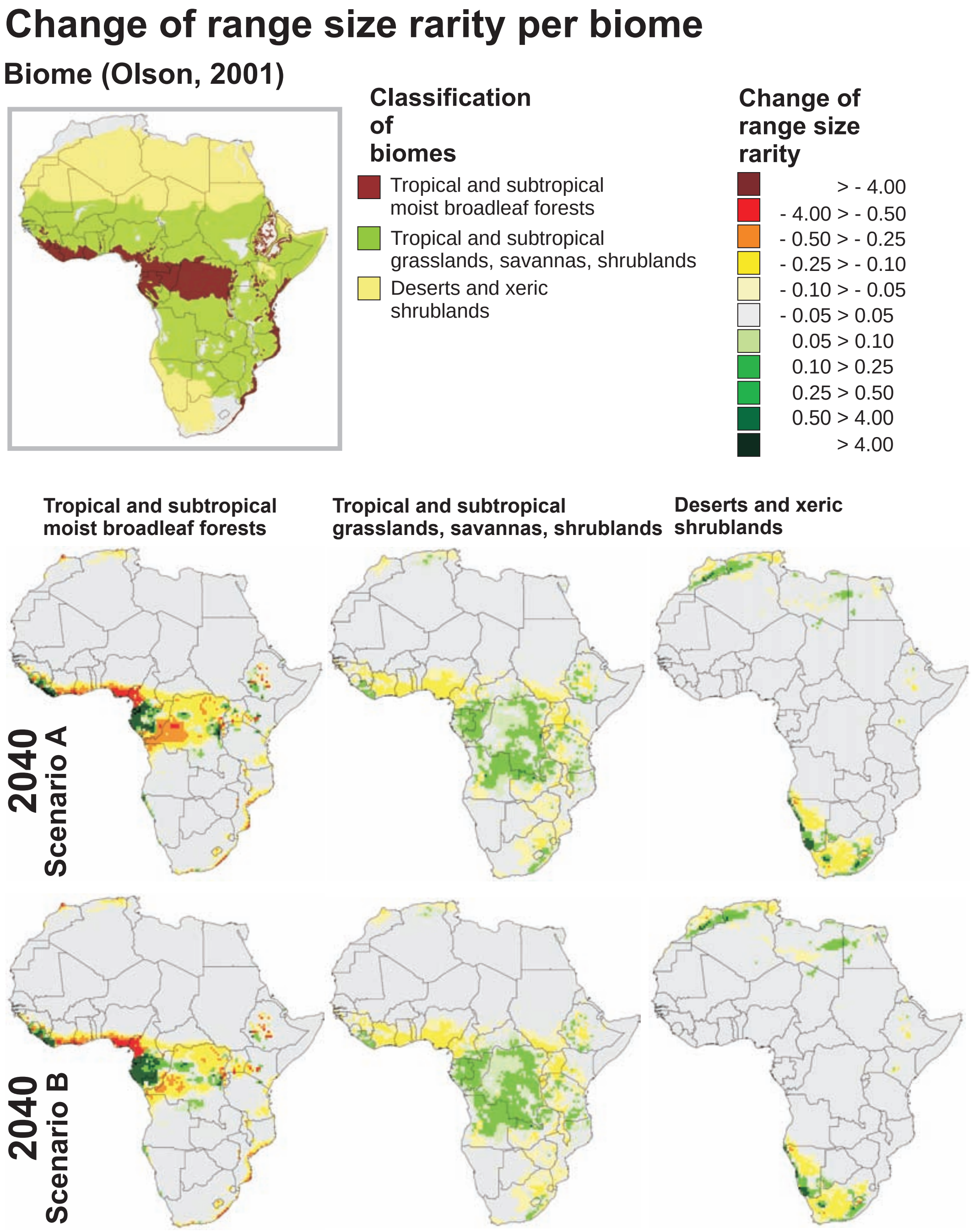


Figure 6.8: Distribution of the three largest biomes of continental Africa (a), and the changes of range-size rarity of species dedicated to the biomes from 2000 to the year 2040 (b). Species are regarded as belonging to a biome if they contribute more than 50% of their entire range to it, and their contribution to rsr within their overall ranges are displayed (classification refers to Olson et al. (2001)). Patterns of range-size rarity refer to the “Markets First” (A) and the “Sustainability First” (B) scenario. Analyses were performed at a spatial resolution of 0.5 degrees.

6.4 Discussion

In this study a methodology was developed that quantifies the impact of land use and climate change on African plant diversity. For that purpose the range-size rarity index was adjusted by the incorporation of species range size reductions due to land use and climate change. The range-size rarity index reflects the sum of the inverse range size of all species occurring within a particular area.

Range-size rarity, species richness and conservation priorities

The improvement of our study compared to existing studies dealing with biodiversity change is the adjustment of the range-size rarity index, also termed as endemism richness. The adjusted range-size rarity considers reductions of the potential range of a particular species due to land use and climate change. An reduction of range size leads to an increase of the relative importance of species remaining ranges. With it the range-size rarity increases per area meaning that the area increases in importance for a majority of species and its conservation.Following, an increase of range-size rarity value does not only indicate an increasing species numbers, but moreover an increasing conservation value in the sense of rarity for the respective species. The relation with area size facilitates to evaluate areas in respect to therein occurring species. Endemism richness can thus be a valuable assistance to the management of natural resources, e.g. when identifying priority areas for conservation (Kier and Barthlott, 2001).

Range-size rarity values across Africa are similar to patterns of vascular plant species richness (Barthlott et al., 2005). Generally high *rsr* values imply for areas that are important in terms of numbers of species. However, the values of species richness also show some different patterns. Results of range-size rarity may be interpreted as the actual and future possible threat to plant diversity, and it may be suggested that plant diversity may change in future on the African continent.

Future projections indicate important changes, due to land use and climate change, most prominent in the “Tropical and subtropical moist broadleaf forests” and the semi-arid “Tropical and subtropical grasslands, savannas, and shrublands” biomes (referring to Olson et al., 2001). Results quantifiable compared to other studies of future biodiversity change show similar projections: A study which developed biodiversity scenarios for 2100 concludes that grasslands and Mediterranean ecosystems will experience the largest biodiversity change caused by land use (Sala et al., 2000). The Millennium Ecosystem Assessment global biodiversity scenarios also project large habitat losses and subsequent loss of biodiversity in savannas, tropical forests and shrublands particularly in Africa (MEA, 2005).

Changes of range-size rarity per area

Impact of land use and climate change. In future, land use expansion and changing climate conditions constitute a combination of threats that are responsible for severe declines in species range sizes in Africa as shown in our analyses. The combined impact is considerably higher than both examined in isolation. The reason can be found in the patterns of land use, which mostly occurs in the savanna regions. Large parts of these regions are completely used for agriculture and with it assumed as not longer suitable for species occurrence. This results in complete loss of range-size rarity within the used areas and an increase of *rsr* within the remaining areas. In future the “Tropical and subtropical grasslands, savannas, and shrublands” will play a growing role for agricultural production, thus the impact of land use on *rsr* will further increase. Consequently a change of land use impacts species more severely than climate change in these regions. The “Tropical and subtropical moist broadleaf forests” are currently and in future to an increasing extent converted into land use areas, but not in such high, extended rates as in the the savanna regions.

Most apparent is an increase of *rsr* considering species that mainly occur in the “Tropical and subtropical moist broadleaf forests”. At the same time, *rsr* of the regarded species decreases in surrounding biomes, mostly from the “Tropical and subtropical grasslands, savannas, and shrublands”. As climate change leads to a rise of temperature, species lose suitable living conditions. Humid rainforests provide conditions for a wide range of species that formerly belong to other regions, where they lose suitable habitats.Further, deserts indicate little changes of range size rarity in respect to climate change. Species are already adapted to extreme conditions such as drought tolerance species.

Limitations of the approach

By incorporating range size rarity, our approach of modelling future impacts of land use and climate change on plant diversity introduces a new qualitative component. The analysis of future biodiversity change is primarily based on the impact of projected land use and climate change in Africa. However, the understanding of species responses to these drivers is still incomplete and some limitations remain in our approach.

A possible underestimation of the impact of land use may occur as an artifact of the modelling approach: The different resolutions of input data could generate consistent differences in the accuracy of estimations. Species data are stored in a binary code (1 or 0) meaning that either species are present or absent per grid cell (50 x 50 km). This fact definitely overestimates the decrease in range size in many cases, due to considering large area to be suitable for species occurrences, and results in much more pessimistic future predictions. On the contrary, land use impact is estimated as percentage per grid cell (rescaled from 10 x 10 km to 50 x 50 km). This leads to more accurate results, due to using data referred to a higher resolution. Accordingly, data are not overestimated, resulting in lower impact values.

Further, a spatial resolution of 0.5 degrees, as we use in our analyses, disregards locally restricted habitats such as remaining pockets of (semi-) natural vegetation, where species still may be able to persist, even though the overall climate conditions are getting suitable.

In our study we state a very drastic assumption that areas under land use are not longer suitable for species occurrence at all. In contrast, remaining areas are seen as not impacted, which underestimates their impact value. Our approach ignores further aspect that to have an overall impact on plant diversity: For example, the responses of species interactions and populations, and also long-term impacts on plant species such as nitrogen deposition and pollution were not considered in our model (Thomas et al., 2004; Broennimann et al., 2006; Thuiller et al., 2006).

However, incorporating such factors would result in even negative projected plant diversity change than presented here. Especially those areas would be affected that are facing only minor negative impacts in our approach. This calls for the integration of more comprehensive aspects in respective future studies.

6.5 Conclusions

Climate change may pronouncedly affect habitat suitability. The combined occurrence of land use and climate change constitutes an even amplified risk for plant species persistence. Important indicators for conservation are, among others, high species richness and the amount of rare species. The challenge is to locate and prioritize areas in order to best determine conservation strategies. The major requirements for species conservation are the preservation of intact habitats and to minimize negative impacts of climate and land use change. We found that species' habitat suitability decline in response to the interaction between land use activities and climate change. The potential change of suitable habitats of species in terms of endemism richness. This calls for a priorisation of certain hotspots of particular high species richness and endemism. The used amplified indicator measures the conservation value of particular areas and quantifies the impact posed by land use and climate change on plant diversity patterns. The examination of "range-size rarity" evaluates both threats in combination and each of both in isolation in continental Africa. The index provides a better measure of the conservation value of an area, and calls for concentrations on necessary conservation hotspots.

The analysis reinforces the need for better understanding the long-term impacts of projected land use and climate change on species range sizes. However long-term projections of complex processes such as biodiversity change will remain inherently uncertain. Thus, the presented results enhance the possibility to refine priority areas for conservation, and serve as a valuable indicator to improve nature conservation and management policy.

CHAPTER 7

General conclusions

Land use, climate change and the associated habitat conversion have a considerable impact on plant diversity patterns on the African continent. The present study aims at a better understanding of the impact of the driving forces of species diversity changes, and their possible implication. It is shown that, despite all methodology limitations and uncertainties, it is possible to gain relevant insights in the relationship between species distributions, land use and climate change at a macro-scale. The corresponding challenge calls for more interdisciplinary approaches that incorporate different research disciplines for the development of sustainable strategies to conserve biodiversity.

Recently, there has been considerable ecological research that aims to estimate future changes of biodiversity patterns. However, species responses to environmental changes are complex and still not well understood. Several approaches already exist that give projections of the response of species to land use and climate variation (Chapter 3). None of them delivers a scientific method that combines the effects of land use and climate change, and furthermore none is adequate for producing quantitative projections of future biodiversity patterns from current knowledge. Synthesizing all approaches integratively demonstrates that many useful studies already exist and are waiting for integration, application and implementation. Assuming an average result of all studies discussed here, it is likely that the CBD target of *significantly reducing the rate of biodiversity loss at the global level* is not reached by the targeted year 2010 and will neither be reached in the near future. Further it is projected that most of the identified direct drivers of biodiversity loss either remain constant or will increase.

The loss of biodiversity will not be reduced by more general descriptive studies and will not wait for the development of new approaches or their implementation into environmental policy. Decisive and precise scientifically based assessments are needed for safeguarding biodiversity and setting conservation priorities. For that purpose, more collaboration between scientists of biodiversity issues and conservation such as ecological modellers, remote-sensing researchers, and field biologists, is inevitable.

The application of an integrative approach enhances the evaluation of biodiversity patterns demonstrated by the combination of two different disciplines (Chapter 4). The incorporation of classical environmental niche models and land cover data show the potential to deliver estimations of the actual species distribution. Consideration of land cover information improves results by drastically delimitating the distribution of potentially suitable habitats. Besides the approximation of actual species distribution, further consequences on the overall habitat quality can be delivered. We showed exemplarily for West Africa that habitats suitable for woody species predominantly decreased during one decade, and are under severe land cover change-induced threat. This demonstrates the potential of the developed approach to identify areas where land cover changes and centers of biodiversity coincide and, equally important, over which time-span these changes occur. Thus, the approach is useful as a spatially and temporally explicit tool for monitoring biodiversity. Moreover, it allows the evaluation and qualification of the status of protected areas with respect to their current significance for conservation. As an outlook, in addition to the quantification of deforestation, the integration of socio-economic factors would enhance its understanding. In that context, based on actual land cover patterns dynamic models facilitate the projection of future habitat dynamics. The application of such factors can help to identify related challenges in agriculture policy, the plantation economy, intensive agricultural production and the land right system.

An understanding of the various and complex responses of species to human impact is urgently needed to define effective conservation strategies. An important step towards this goal is to quantify continent-wide the impact of land use on plant habitats, as land use is assumed to be a main driver of biodiversity loss on the macro-scale (Chapter 5). Land use does not definitely enforce species extinction, rather it causes a reduction of the size of suitable habitats of species. Already today, suitable habitats may be dramatically constricted. In future, an increasing number of species habitats may be threatened that are currently not in danger. It is therefore urgently necessary to consider possible future developments of land use for the evaluation of the species' threat status. In respect to estimated future threats the high conversion rate of native habitats calls for strong and immediate action by precising conservation priorities. Assuming that there is no difference in the responses of species and ecosystem depending to different land use practices, this approach yields reliable insights into the impact of land use on species diversity at a continental scale.

In addition to land use, climate change may pronouncedly affect habitat suitability. The combined occurrence of land use and climate change constitutes an even amplified risk for plant species persistence. Important indicators for conservation are, among others, high species richness and the amount of rare species. The challenge is to locate and prioritize areas in order to best determine conservation strategies (Chapter 6). The major requirements for species conservation are the preservation of intact habitats and to minimize negative impacts of climate and land use change. We found that species' habitat suitability decline in response to the interaction between land use activities and climate change. The potential change of suitable habitats of species in terms of endemism richness. This calls for a priorisation of certain hotspots of particular high species richness and endemism. The used amplified indicator measures the conservation value of particular areas and quantifies the impact posed by land use and climate change on plant diversity patterns. The examination of "range-size rarity" evaluates both threats in combination and each of both in isolation in continental Africa. The analysis reinforces the need for better understanding the long-term impacts of projected land use and climate change on species range sizes. However long-term projections of complex processes such as biodiversity change will remain inherently uncertain. Thus, the presented results enhance the possibility to refine priority areas for conservation, and serve as a valuable indicator to improve nature conservation and management policy.

Safeguarding the world's current and future biodiversity demands for the development of initiative concepts, a process that is ambitious and challenging. The presented approaches incorporate important assessments to evaluate the status of plant diversity and emphasize the need for more target-oriented conservation planning. Altogether, they contribute to the development of new methodological approaches and are a further mosaic for a better understanding of biodiversity responses to human induced threats.

CHAPTER 8

Summary

Sabellek, Katharina (2010): Impact of Land Use and Climate Change on Plant Diversity Patterns in Africa. Doctoral thesis, Mathematisch-Naturwissenschaftliche Fakultät, Rheinische Friedrich-Wilhelms-Universität Bonn. 139 pp.

This thesis examines the impact of land use and climate change on plant diversity patterns across continental Africa at different spatial and temporal scales. The study builds upon previous work conducted at the Nees Institute for Biodiversity of Plants (University Bonn) in the frame of the BIOMAPS working group and is embedded in the BIOTA West project (funded by the German Federal Ministry of Education and Research).

African plant diversity is strongly threatened by land use and climate change. The growing future demand for food and energy in combination with a climate-change induced decrease in yield will lead to an expansion of agricultural areas. In addition, climate change may reduce habitat suitability within the remaining areas and induce shifts of species ranges. Comprehensive concepts that integrate biodiversity conservation and the facilitation of sustainable human development require appropriate methodical approaches and monitoring schemes.

Interactions between land use and biodiversity are complex and not completely understood. Various approaches to incorporate biodiversity change by broad scale global change models are compared. It is recognized that no reliable and scientific concepts exist that are able to comprehensively include all relevant drivers of diversity loss. The implementation of species interactions, composition and adaptation, according to land use type, intensity and extent, contributes to an improved understanding of species responses to land use-change, and is still not properly dealt with. For that purpose, interdisciplinary collaborations are required in order to develop joint approaches at the interface between broad scale land use and biodiversity modelling.

The integration of land cover change information considerably improves classical species distribution models by delimitating habitat suitability for species and estimating the quality of habitats. Results for a set of woody species in West Africa indicate a decline of their habitat quality by 65% due to woodland cover changes in the reference period from 1990 to 2000. In contrast, within protected areas, local habitat loss is overcompensated by a general improvement of habitat quality by 63%. The approach highlights the benefit of combining the expertise of two different disciplines, remote sensing and macroecology. It is an improvement for the evaluation of habitat quality inside and outside protected areas, and for the spatially and temporally explicit monitoring of biodiversity loss.

Habitat conversion, fragmentation and destruction, may cause a severe decline of species ranges. Until 2050, a considerable proportion of plant species occurring across continental Africa is of particular threat by land use change-induced pressure on their habitats. Potential species range sizes decrease from 63% in 2000 to 56% in 2050 in average. While land use activities predominantly affect range-restricted species today, the assumed future expansion of land use areas may additionally impact the ranges of more widespread species that are located in regions of prospected land use intensification.

In addition to land use change, climate change is responsible for considerable shifts in geographic size and distribution of species ranges. Accordingly, the reduction of the potential range of a particular species leads to an increase of the relative importance of its remaining range. The range-size rarity index reflects the sum of the inverse range size of all species occurring within a particular area. Shifts in range size rarity for 3,144 plant species due to either land use or climate change and for both in combination for continental Africa were considered. Today, areas housing a large proportion of overall species ranges are located in lowland rainforests and the Afrotropical mountains. Due to the combined effect of land use and climate change, the contribution of many lowland areas the overall species ranges decreases pronouncedly. In contrast, the relative importance of Afromontane areas, the Angolan escarpment, and the Namibian coast to represent overall species ranges increases. The approach facilitates a better measure of the conservation value of particular areas in respect to the future impact of land use and climate change. Thus, the presented results contribute to refine priority areas for conservation, and serve as a valuable indicator to improve nature conservation and management policy.

This thesis incorporates assessments of the current and future threat of land use into the evaluation of the status of plant diversity and emphasizes the need for more target-oriented conservation planning. Altogether, it contributes to the development of new methodological approaches for a better understanding of the impact of land use and climate change on plant diversity patterns in Africa.

CHAPTER 9

Zusammenfassung

Sabellek, Katharina (2010): Impact of Land Use and Climate Change on Plant Diversity Patterns in Africa. Dissertation, Mathematisch-Naturwissenschaftliche Fakultät, Rheinische Friedrich-Wilhelms-Universität Bonn. 139 Seiten.

Die vorliegende Arbeit untersucht den Einfluss von Landnutzung und Klimawandel auf die Muster der Pflanzendiversität des kontinentalen Afrikas auf verschiedenen räumlichen und zeitlichen Skalen. Die Studie basiert auf Arbeiten, die am Nees-Institut für Biodiversität der Pflanzen (Universität Bonn) in der Arbeitsgruppe BIOMAPS durchgeführt wurden, und ist in das Projekt BIOTA West eingebettet (gegründet vom Bundesministerium für Bildung und Forschung).

Die Pflanzendiversität in Afrika ist durch Landnutzung und Klimawandel bedroht. Die zukünftig nachwachsende Nachfrage von Nahrungsmitteln und Energie, in Kombination mit einem vom Klimawandel verursachten Rückgang der Ernteerträge, kann in Zukunft zu einer Ausdehnung landwirtschaftlich genutzter Flächen führen. Darüber hinaus kann der Klimawandel zu einer Verminderung der Habitateignung innerhalb der verbleibenden Flächen führen sowie eine Verschiebung der Artareale verursachen. Umfassende Konzepte, die den Schutz der Biodiversität und die Option für eine nachhaltige Nutzung integrieren, erfordern den Aufbau methodisch geeigneter Monitoring-Ansätze.

Die Wechselwirkungen zwischen Landnutzung und Biodiversität sind komplex und nicht vollständig verstanden. In dieser Arbeit wurden Modellierungsansätze, die Veränderungen der Biodiversität in die Modellierung des “Global Change” auf kontinentaler und globaler Ebene einbeziehen, miteinander verglichen. Daraus geht hervor, das kein umfassendes, wissenschaftlich anerkanntes Konzept existiert, das alle relevanten Faktoren des Diversitätsverlustes umfassend einschließt. Die Einbeziehung von Wechselwirkungen zwischen Arten, deren Zusammensetzung und Anpassungsfähigkeit, bezogen auf den Typ, die Intensität und die Ausdehnung der Landnutzung, trägt zu einem verbesserten Verständnis bei, und wurde bisher nicht ausreichend behandelt.

Interdisziplinäre Zusammenarbeit ist erforderlich, um die Wechselwirkungen zwischen Landnutzung und Biodiversität auf kontinentaler und globaler Ebene zu modellieren.

Die klassische Artverbreitungsmodellierung wird durch die Einbeziehung von Informationen zur Änderung der Landbedeckung wesentlich verbessert, wodurch der Einfluss auf Habitateignung für Arten und die Habitatqualität abgeschätzt werden kann. Ergebnisse für eine Gruppe holziger Arten in Westafrika deuten auf einen Rückgang ihrer Habitatqualität um 65% hin, verursacht durch die Veränderung der Waldbedeckung im Referenzzeitraum von 1990 bis 2000. Im Gegensatz dazu wird innerhalb der Schutzgebiete der Verlust auf lokaler Ebene durch eine Verbesserung der Habitatqualität von 63% kompensiert. Der Ansatz unterstreicht den Nutzen der Kombination zweier Fachdisziplinen, der Fernerkundung und der Makroökologie. Dies trägt zu einer verbesserten Bewertung der Habitatqualität innerhalb und außerhalb von Schutzgebieten und zu einem detailliert räumlichen und zeitlichen Biodiversitäts-Monitoring bei.

Konvertierung, Fragmentierung und Zerstörung von Habitaten können Gründe für eine drastische Verkleinerung von Artarealen sein. Bis zum Jahr 2050 ist ein beachtlicher Anteil der Pflanzenarten, die im kontinentalen Afrika vorkommen, auf Grund des Landnutzungsdruckes auf ihre Habitate besonders gefährdet. Im Vergleich zur potentiellen Größe der Artareale verkleinert sich diese durchschnittlich auf 63% im Jahr 2000 und 56% im Jahr 2050. Während Landnutzungsaktivitäten heute vorrangig kleinräumig verbreitete Arten betreffen, wird für die Zukunft angenommen, dass eine Ausweitung von Landnutzungsflächen zusätzlich Einfluss auf weiträumig verbreitete Arten hat.

Zusätzlich zum Landnutzungswandel ist der Klimawandel verantwortlich für maßgebende Veränderungen in Größe und Verbreitung der Artareale. Demzufolge führt eine Verringerung der Arealgröße zu einem Anstieg der relativen Wichtigkeit innerhalb der verbleibenden Fläche. Die “range-size rarity” beschreibt die Summe der inversen Arealgröße aller Arten, die zu der Fläche beitragen. Verschiebungen der “range-size rarity” durch entweder Landnutzung oder Klimawandel und für beide in Kombination wurden für 3,144 Pflanzenarten für den Kontinent Afrika betrachtet. Die größten Proportionen von den gesamten Artarealen beherbergen heute überwiegend die Tieflandregenwälder und die afrotropischen Gebirge. Durch die Kombination der Faktoren Landnutzung und Klimawandel sinkt der Beitrag der gesamten Artareale in vielen Gebieten im Flachland. Im Gegensatz dazu steigt die Wichtigkeit der afromontanen Gebiete, des angolischen Eskarpments und der namibischen Küsten, die die gesamten Artareale repräsentieren. Diese Ansatz ermöglicht eine bessere Beurteilung von Schutzwerten bestimmter Flächen in Hinblick auf zukünftige Landnutzung und Klimawandel. Somit präsentieren die Ergebnisse einen Beitrag zur Verfeinerung der prioritären schützenswerten Flächen, und dienen als ein Indikator zur Verbesserung von Naturschutz und Managmentregelungen.

Die durchgeführten Modellierungen verdeutlichen den Einfluss der heutigen und zukünftigen Bedrohung von Biodiversität durch Landnutzung und zeigt einen erhöhten Bedarf für zielorientierte Naturschutzplanung. Insgesamt trägt diese Arbeit mit methodischen Ansätzen zu einem besseres Verständis des Einflusses der Landnutzung und des Klimawandels auf die Pflanzendiversitätsmuster in Afrika bei.

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BII	Biodiversity Intactness Index
BIOLOG	Research program “Biodiversity and Global Change” of the BMBF
BIOMAPS	Biodiversity Mapping for Protection and Sustainable Use of Natural Resources – Working group at the Nees Institute for Biodiversity of Plants, University of Bonn
BIOTA Africa	BIOdiversity Monitoring Transect Analysis in Africa, Project network within the BIOLOG-Programme
BISAP	Biogeographic Information System on African Plant Diversity
BMBF	German Federal Ministry of Education and Research
CBD	Convention on Biological Diversity
CESR	Center for Environmental Systems Research
GEO-4	Global Environmental Outlook 4
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LandShift	Land Simulation to Harmonize and Integrate Freshwater availability and the Terrestrial environment
LPI	Living Planet Index
Maxent	Maximum entropy probability distribution model
MSA	Mean Species Abundance
NCI	Natural Capital Index
NDVI	Normalized difference vegetation index
NPP	Net primary productivity
rsr	Range size rarity
SRES	IPCC Special Report on Emission Scenarios
UNCBD	United Nations Convention on Biological Diversity
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WDPA	World Database on Protected Areas
WWF	World Wide Fund for Nature