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Developing a Biodiversity Evaluation Tool and Scenario Design Methods for the Greater Mekong Subregion

Dissertation

Submitted in fulfillment of the requirements for the degree
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Presented by

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Developing a Biodiversity Evaluation Tool and Scenario Design Methods for the GMS

Statement of uniqueness

Author's Declaration

I, Marc Cotter, hereby affirm that I have written this thesis entitled "Developing a Biodiversity Evaluation Tool and Scenario Design Methods for the Greater Mekong Subregion" independently as my original work as part of my dissertation at the Faculty of Agricultural Sciences at Hohenheim University.

All the authors in the quoted or mentioned publications in this manuscript have been accredited. No piece of work by any person has been included without the author being cited, nor have I enlisted the assistance of commercial promotion agencies. This thesis has not been presented into other boards for examination.

Marc Cotter	Stuttgart, 09.09.2011

This thesis was accepted as a doctoral dissertation in fulfilment of the requirements for the degree "Doktor der Agrarwissenschaften, Dr.sc.agr." by the Faculty of Agricultural Sciences at the University of Hohenheim on the 2nd of December 2011.

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Examination committee

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Overview of publications

In order to comply with the regulations for a cumulative PhD thesis at the Faculty of Agricultural Sciences, several publications have been included into this work. As these publications have been edited to fit the regulations of different publishers, the style for quoting and the layout of the reference section may vary between chapters.

Chapter 2:
Marc Cotter, Konrad Martin, Joachim Sauerborn (2009). How Do „Renewable Products“ Impact Biodiversity and Ecosystem Services – The Example of Natural Rubber in China. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 110:1, 10-23

Chapter 3:
Karin Berkhoff, Marc Cotter, Sylvia Herrmann, Joachim Sauerborn (2009). Use of remote sensing data as basic information for applied land use change modeling. Proceedings of the ERSEC International Conference 2008, Sustainable Land Use and Water Management. 8-10 October 2008, Beijing, PR China, p.36-45.
Own contribution: approximately 25%. A 5 page manuscript on the integration of ecological evaluation tools into the LILAC project had been prepared. Field excursions, GPS-mapping for georeferencing and rectification as well as a survey on land use systems and natural vegetation classes had been included, resulting in the integration of chapter 3.6 of the publication and supplying necessary field data for chapter 3.4.

Chapter 4:
Marc Cotter, Jan Grenz, Liu Jingxin, Gerhard Langenberger, Joachim Sauerborn (expected 2012). A biodiversity evaluation tool for the tropics – modeling concept for planning and conservation. Submitted to PLoS One. current status: in review

Chapter 5:
Marc Cotter, Karin Berkhoff, Tarig Gibreel, Abdolbaset Ghorbani, Reza Golbon, Sylvia Herrmann, Ernst-August Nuppenau, Andreas Wahren, Joachim Sauerborn (expected 2012). Incentive based compensation for a favorable socio-ecological situation: Designing a scenario for sustainable land management. Submitted to Ecological Indicators on 10.03.2011 as part of the Special Issue "Assessment of rural livelihoods in South-West China based on environmental, economic and social indicators".

Chapter 6:
Shikha Bajaj, Marc Cotter, Michael Ahlheim, Joachim Sauerborn (expected 2012). Acceptance of 3D-Visualization techniques in Nature Reserve planning – a case study from Southwest China. To be submitted to the Journal of Landscape Planning in autumn 2011.
Own contribution: approximately 50%. Concept and Integration into LILAC framework. Scenario design and visualization in cooperation with lead author. Questionnaire design in cooperation with all authors. Supervision of the research work, co-authorship and proof-reading of the manuscript.

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1. General Introduction

1.1 Rubber cultivation in the Greater Mekong Subregion

Over the last decades the cultivation of large-scale plantations has had a tremendous impact on the landscapes of South-East Asia. Ranging from the coconut (*Cocos nucifera*) plantations of the Philippines over oil palm (*Elaeis guineensis*) in the Malayan Archipelago to rubber (*Hevea brasiliensis*) cultivation along the Mekong and its tributaries, these commercialized farm systems have changed the way in which mankind interacts with its natural environment. In many cases, century old traditions of sustainable land management and close interactions between human activities and the services provided by natural, mostly forest based, ecosystems have been replaced by modern, streamlined agricultural production systems dependent on world market prices and synthetic pesticide and fertilizer inputs, with hardly foreseeable impacts on the sustainability of agriculture and the provision of much needed Ecosystem Services and Functions (ESS/ESF) for the generations to come.

The Millennium Ecosystem Assessment (2005) defines Ecosystem Services (ESS) as „the benefits people obtain from ecosystems". The Asian Development Bank describes ESS/ESF as "goods and services provided by a natural unit of living things and their physical environment that benefit human beings".

Figure 1.1 Rubber cultivation in the Naban River Watershed National Nature Reserve

Figure 1.2 Impact of the establishment of rubber plantations on landscape structure in NRWNNR

In the northern parts of the Greater Mekong Subregion (GMS) where our research area in Xishuangbanna, Yunnan, PR China is located, rubber is mainly cultivated in the lowland areas of the Mekong stream system below 1000 m a.s.l., mostly due to cold spells during the dry season in winter that greatly reduce the potential for the establishment of rubber seedlings, but also the expected yields in these highland areas. Likewise rubber cultivation as a land use class (LUC) has replaced orchards, vegetable farming, tea plantations and maize based cropping systems in these areas, but especially tropical seasonal rainforests have been hit hard by the expansion of agricultural activities. Li et al. (2007) reported that during the period from 1976 to 2003 67% of these forests vanished in Xishuangbanna, whereby at the same period the proportion of rubber cultivation in Xishuangbanna increased from 1.1% to more than 11% of the prefecture's total area.

The research area, to which the presented models and scenario building methodology are applied, is the Naban River Watershed National Nature Reserve (NRWNNR, 22°08'N 100°41'E) in the province of Yunnan, PR China. Yunnan is part of the Indo-Burmese "hot-spot of biodiversity" (Myers et al. 2000). The nature reserve covers 271 km² and its elevation ranges from 500 m to 2300 m above sea level. It is covering the watershed of the Naban River, which is a tributary of the Mekong River (Lancang Jiang). It features an especially high diversity of natural vegetation types, as well as hosts a big variety of land use systems due to the topographically and ethnically diverse history of the region (Zhu 2008).

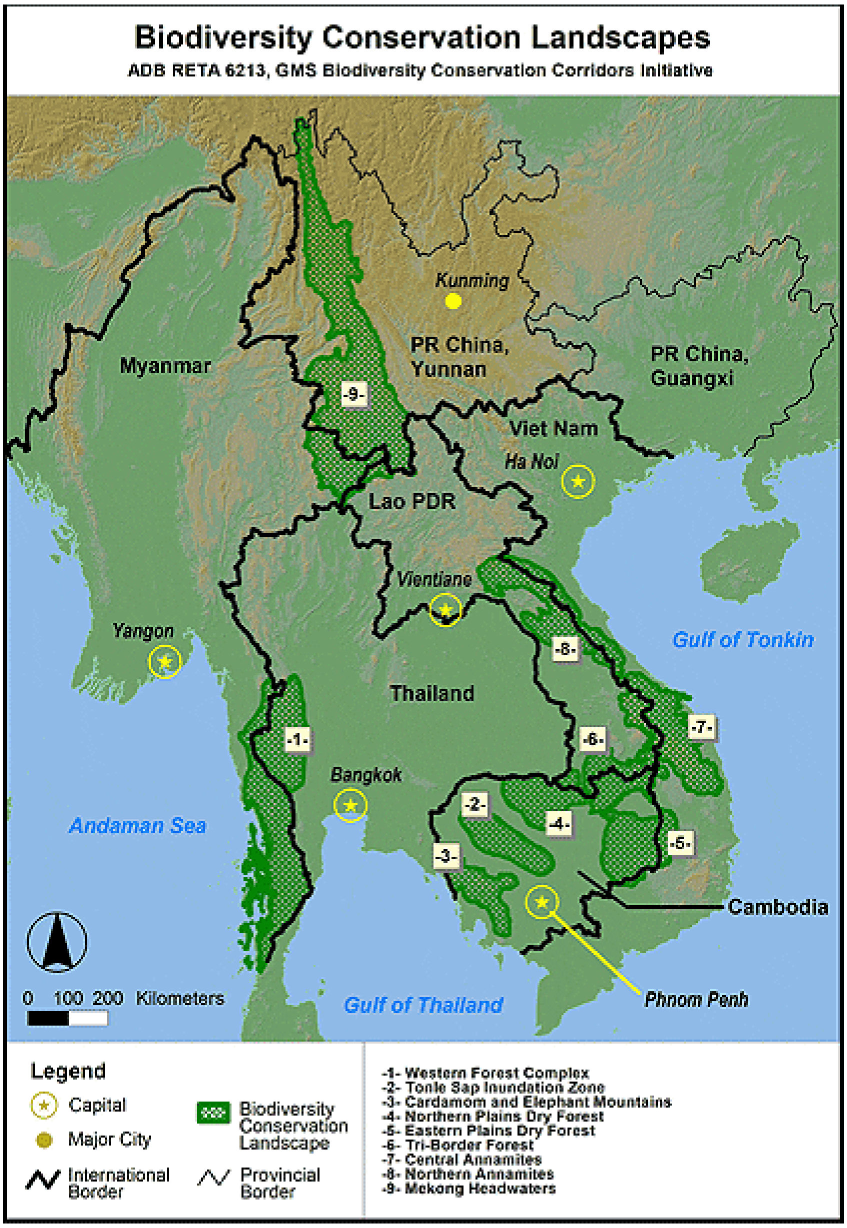

Figure 1.3 The Greater Mekong Subregion (GMS) and the conservation sites of the GMS Biodiversity Conservation Corridors Initiative. Map provided by Asian Development Bank Biodiversity Conservation Corridor Initiative, via www.adb.org

According to Xu et al. (2005) the introduction of rubber to Xishuangbanna was mainly driven by state owned rubber farms after China's "Great Leap forward" (after 1961) with the migration of several hundred thousand Han Chinese as farm workers and militia to the Xishuangbanna Prefecture. Local population at that time consisted mainly of Dai, Hani or Bulang minorities, the first mainly consisting of lowland farmers, traders and the ruling classes of pre-socialist times, the latter living in the uplands areas as semi-nomads practicing slash-and-burn agriculture, tea forestry and livestock farming. After the first wave of rubber establishment in the 1960s and 1970s, more and more small scale farmers began adopting rubber as a cash-crop, with changes in land tenure laws and forest allocation to individual farmers greatly facilitating their efforts. Nowadays, two thirds of the rubber area in the Jinghong County is managed by state-owned rubber companies, one third is small-scale private rubber farming. For more detailed information on the history of rubber cultivation in Xishuangbanna, see Xu et al. (2005).

Figure 1.4 Dai minority “Holy Hill” in the lowland rubber cultivation areas of NRWNNR near the village Mandian. A rubber plantation’s canopy can be seen on the far right, directly adjacent to the remaining secondary forest stands.

The introduction of rubber to the GMS has not only had an effect on land cover, but also on the rural population. Rubber farming is a major source of income, with monetary gains far above the usually given income rate of traditional land use systems. Tang et al. (2009) stated in their analysis of the impacts of rubber cultivation that together with the introduction of high yielding hybrid rice varieties, the change from traditional shifting cultivation methods towards permanent rubber cultivation has greatly increased the yearly income of farmers to up to 2000 Yuan/mu (approx.3000 Euro/ha), despite high investments needed in fertilizer and pesticides. Rubber farmers adopted a more sophisticated lifestyle, with motorcycles, TV-Sets, cell phones and refrigerators becoming more and more common. At the same time, vegetable production and pig or cattle breeding have been largely abandoned, leading to a dependency on regional markets and traders coming into the villages. The accompanying improvement of infrastructure (mainly roads) has reduced the travel time to regional towns, but also to institutions of education and healthcare. On the other hand, Tang et al. (2009) also reported negative impacts on the social structure and customs of the local population. Cultural heritages and traditions are being neglected (e.g. Dai Holy Hills, fig. 1.4) and the economic inequality between rich lowland rubber farmers and poor upland farmers widen.

1.2 The LILAC project

As most of the scientific work presented in this dissertation is closely related to the activities of the Living Landscapes China LILAC project, I will give a brief overview on the project's aims and scientific framework. The overall goal of the LILAC project was to develop models and tools for the evaluation of possible future land use decisions on the socio-cultural, economic and ecologic framework of the research area. By using newly developed or regionally adapted modeling approaches as well as interdisciplinary scenario design procedures, the project wanted to combine research done by various fields of science in order to highlight possible alternative pathways and their consequences on man and nature alike. By coupling the disciplinary research and modeling activities with the help of models designed to simulate farmers decision making processes as well as the resulting land use allocation patterns, the LILAC project's modeling framework allows for a multi- and interdisciplinary assessment of land use change in the rural areas of Xishuangbanna rubber growing area, and beyond. As the NRWNNR is managed according to the principles of UNESCOs "Man and the Biosphere" program, the region offers great possibilities to be used as a comprehensive example for the GMS's interactions between man's desire to secure his livelihood and the necessity to protect the habitat of a multitude of species in this biodiversity hotspot, but also the functions and services provided by nature.

The project duration was from autumn 2007 to winter 2010, with field work taking place all throughout the period. Scientists from the fields of ecology, economics, social sciences, land use planning and hydrology conducted their studies, interviews, field trips and workshops in the NRWNNR with a final symposium being held in October 2010 at our partner institution, the Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences.

The field data used for the development of the model and methods presented in this thesis is part of the research activities of our subproject ECOL-B. The raw data of the field studies conducted by our entomologists and botanists have formed the basis of the biodiversity evaluation tool. This data has been combined with information from remote sensing and satellite imaginary to allow for an assessment of the state of diversity within our research area. More information can be found in chapter four.

One main goal of the project was to provide scenarios on how future land use options for the NRWNNR can look like, and what consequences these would have on the human population, it's economic and social structure, but also on hydrology and biodiversity. In order to do this, the results, findings and experiences of the different research groups have been combined to create future land use scenarios. The result of these efforts is currently being published as a special issue of the journal "Ecological Indicators", parts thereof can be found in chapter five. In this chapter, my co-authors and I present the methodology that we have designed in order to be able to combine the disciplinary assessments into an interdisciplinary scenario storyline that has been parameterized with scientific data derived from our research activities of the last three years.

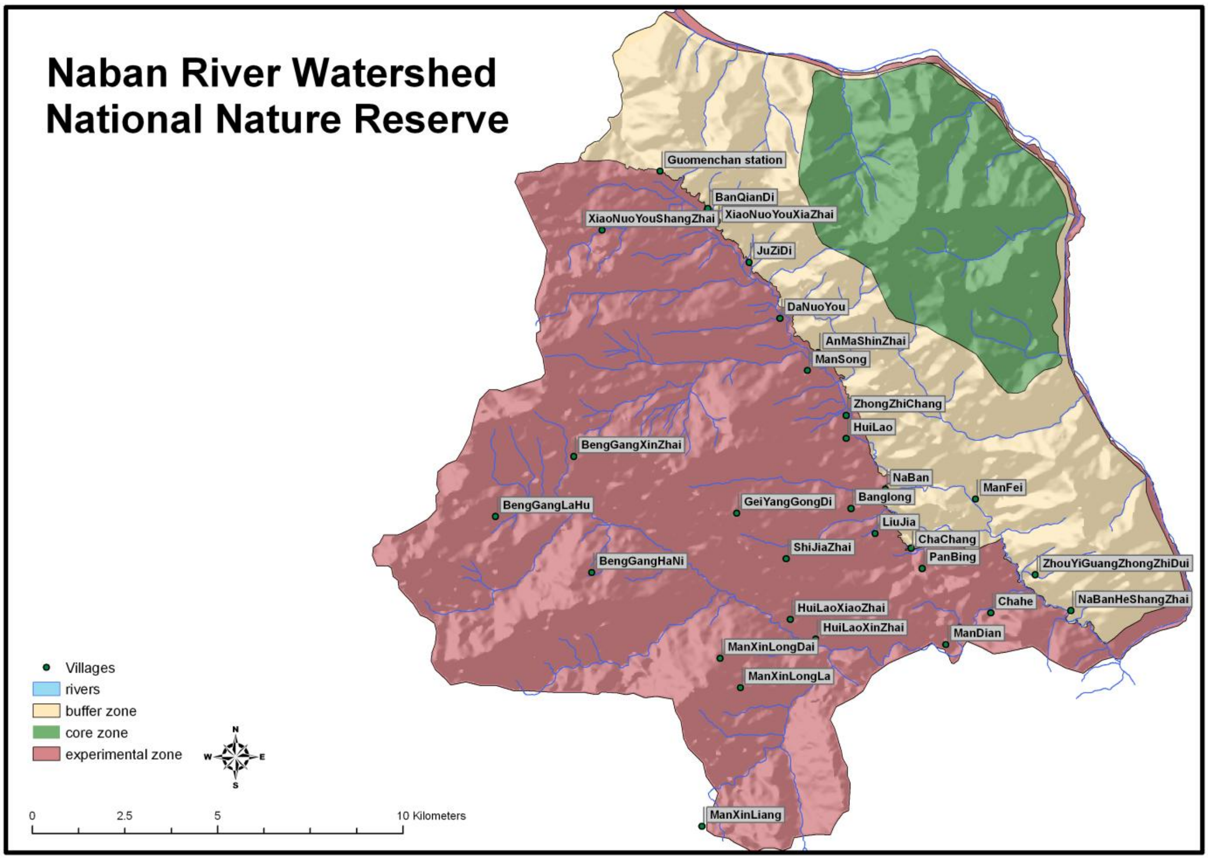

Figure 1.5 Naban River Watershed National Nature Reserve, overview of the three conservation zones (core, buffer, experimental) and topographic features represented with a hill shade.

1.3 Ecological evaluation

The magnitude and speed of man-driven land use changes seen over the course of the 20th century has led many researchers, administration officials and politicians to call for and develop models and procedures to reliably measure the impacts of these changes on local and regional ecology. As an example, the Council of the European Union has stated in its' "3002nd council meeting: environment" that the "EU intends to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss" (Council of the European Union 2010).

Ecologists often face the problem that detailed analyses of flora and fauna for a given research area are time consuming, need trained specialist personal for field work and data evaluation and thus end up quite demanding from a monetary perspective. When combining these factors with a number of challenges faced when up-scaling research data from plot to regional levels and when transferring concepts from one research area to another, even close by, it is quite comprehensible that a wide spectrum of possible approaches, many in the form of computer based models, have been created, assessed and implemented to tackle these problems throughout the last decades. A much used example for these models and indices derived from them, thematically narrowed as it may be, is the World Conservation Unions IUCN red list index, and the various adapted and revised versions of it (see e.g. Butchart et al., 2007). Within these sets of indices, scientists evaluate local biodiversity considering the occurrence and abundance of rare species within given research areas in regard to the species' risks of extinction. These and similar indices are already widely used especially in nature reserve administration on local and regional scales, but also in landscape planning procedures on national and international levels in order to plan nature conservation sites as well as to highlight the potential impacts of land use decisions on local and regional rare wildlife.

Another set of indicators for the evaluation of biodiversity focus on the magnitude of human impact on pristine environments. On a local level, Machado (2004) applied this concept in his "index of naturalness" for the evaluation of the integrity and stability of island based ecosystems from the Galapagos and Canary Islands. By categorizing the vegetation communities found in the research area into classes from 0 (artificial system) to 10 (natural system) using different factors such as e.g. the species composition between native and exotic plants, the amount of artificial alteration (streets, canals) or the intensity of resource input to and output from the system, Machado computed the naturalness of a research area. The results were evaluated graphically as maps of the islands or scale bars representing the distribution of naturalness classes within a research area. On a more national scale closer related to our research area, Trisurat (2010) applied and adapted the GLOBIO3 model (Alkemade et al. 2009) to the mountainous region of northern Thailand, an area facing similar challenges as most parts of the GMS. By combining literature reviews on local pristine vegetation with remote sensing data and administrative maps of villages, built-up areas and especially road networks they developed a model simulating the impact of these infrastructural enterprises on local biodiversity. The "relative mean species abundance" index of remaining species in comparison to species composition from close-to-natural habitats was used in this study to assess the intactness of habitats. This assessment was coupled to dynamic modeling using Dyna-CLUE for the determination of spatial patterns in future land use change scenarios. See also chapter 4.5 for more discussion on this topic.

1.4 Land use scenarios

Land use scenarios are in frequent use especially in the fields of landscape planning, rural development and in public administration. The goal of these scenarios is to communicate the effects of current or past decision making processes on the landscape in the future, mostly to visualize the effects of land use change on a certain area. Based on these scenarios the impact on economy, ecology and social aspects can be evaluated. But in order to derive credible scenarios of future land use, various aspects have to be considered, ranging from data availability, data quality, selection of the most fitting scenario design methods as well as possible biases towards desired results from the developing agencies, but also from the evaluating stakeholders.

The development of storylines forms the basis for comparative scenario analyses. These storylines should depict possible pathways for future developments that, in the best of cases, each individually possess a high amount of probability and represent credible alternatives. Storylines usually vary in the impact and intensity of only a few guiding parameters, that have been identified as the main driving factors for land use change within an area, such as a stricter implementation of laws for nature protection or market prices for certain goods. Starting from a common base, most often a so called baseline scenario that represents the "status quo", these storylines implement gradual changes in the driving factors resulting in different scenarios. The time span can vary, from only a few months to centuries, depending on the area of research and the topics to be addressed. Rural decision making between cropping patterns usually develops faster than global warming or continental drift. The result is, in most cases, a map of the possible future distribution of the analyzed characteristics, in case of our study, possible future land use.

A storyline, in this context, describes possible changes in framework conditions within and beyond the research area, such as changing prices on the world market or drastic policy decisions.
Consequential, scenarios are the results of a storyline affecting the research area over multiple years. Most often, these scenarios are visualized with maps for better communication of key changes.

The ways to get from the baseline to a future land use scenario can be very different, ranging from a more result-oriented approach for the assessment of hedonistic aspects or as add-on to a more complex problem, similar to the one presented in chapter six, over a participatory approach including stakeholder attendance and multiple workshops up to a detailed methodological approach that tries to reduce as many uncertainties as possible by integrating a multitude of scientific disciplines. Obviously, the amount of preliminary work and the quality of scientific data needed varies between the different approaches. An example for multidisciplinary scenario development that has taken over three years of field work from more than 20 scientists actively collecting information on ecology, economy, social structures and land use policies is presented in chapter five.

All of these approaches have one thing in common. They are possible future land use scenarios, valid only within the restricted guidelines set up by their different storylines and the different methods chosen. As a scientist, one can try to reduce the uncertainties to reach an ever increasing credibility for one scenario by integrating more aspects from climate change to global market forecasts, but a simple thing like the introduction of a pest beetle or the ban on certain herbicides can render a whole storyline, and therefore the resulting scenario invalid.

1.5 Visualization techniques in landscape planning

Visualization techniques have a long history in landscape planning. The first pioneers in visualization have been the architects and gardeners of various English landscape parks in the 17th century using painting of noblemen's gardens with interchangeable details such as groves, lakes or bridges in order to better explain the visual impact of gardening decision. A modern and often misused variety of this technique is the photomontage. The computer age has opened the stage for computer-aided design (CAD) based modeling of houses, bridges or wind-mills, and for a variety of computer based animation programs such as the Visual Nature software used in chapter six. These programs offer the possibility of having an observer standing "inside" the visualization, with nearly complete freedom of choosing which angle, direction or spot to look from, hence the name 3D-visualization.

A true 3D-visualization is possible with complex software solutions, but expensive laboratory set-ups are needed to have a wider audience experience this freedom. So, in most cases, the visualization is confined to two dimensions, but taking features such as topography and the height of buildings, cliffs or trees into consideration to create a "virtual" 3D effect similar to what we are used to seeing on TV screens.

Irrespective of the medium chosen, the aim of all visualization techniques is to facilitate the communication of concepts to a wider public. Landscape visualizations which are used to communicate existing conditions and alternative landscape scenarios, past and present for both educative and consultative purposes (Priestnall and Hampson, 2008), mainly because these techniques can bring large data sets to life and enable people to become part of an interactive decision-making process (Pettit et al., 2011).Especially in landscape planning, a discipline where heated debates between agitated local interest groups and communal or private planners a common on topics such as bypasses or wind power stations, computer based visualization techniques can help to inform stakeholders about the expected results. There are cases though were either biased approaches or even deliberate misinformation have caused widespread malcontent and to a certain extend have damaged the reputation of these techniques.

1.6 Objectives

The objectives of this study were to (a) analyze and evaluate the effect of large-scale rubber cultivation on local and regional biodiversity by (b) developing methods to integrate field studies from various disciplines into a comprehensive assessment model. This model was used to highlight key aspects of anthropogenic influence on the composition of species within the NRWNNR and to (c) identify possible impacts of alternative land use decisions. Furthermore, (d) the development of an interdisciplinary approach to scientific scenario design methods has been supplemented with a study on the (e) acceptance of 3D-visualization as a widely unfamiliar communication tool for land use planning in the background of nature conservation sciences.

1.7 Outline of this thesis

In chapter two, an overview of the agronomical and ecological aspects of rubber cultivation is given. Literature sources referring to the impact of different cultivation systems on natural biodiversity are discussed and an introduction to the effect of rubber cultivation on ecosystem services is given. In the second part of chapter two, a method for extrapolating the regionally adapted carbon capture properties of rubber cultivation under suboptimal growth conditions is presented and a comparative assessment is made on the establishment of rubber plantations in regard to the preexisting vegetation. Identifying some of the mayor challenges for nature protection in the context of the rapid expansion of rubber cultivation is one of the goals of this chapter, as well as presenting some possible (and rarely used) alternatives to the common replacement of forest ecosystems by plantation farming.

As a short introduction to the interdisciplinary framework in which this study was conducted, chapter three is giving a concise overview over the pit-falls and difficulties faced when establishing an interdisciplinary model for land use change with special focus on the combination of spatially explicit remote sensing data with transect or point-based ecological as well as qualitative socio-economic data. Within the framework of the LILAC project we have developed our biodiversity evaluation tool. By combining some of the findings discussed in chapter two with our research group's own ecological field work we have been able to design a methodology for up-scaling plot based data on plant species diversity and combining them with landscape metrics. This method was developed and tested with the comparative assessment of a linear extrapolation land use scenario and multiple alternative land use scenarios over the course of three years. This work is being presented in chapter four. The findings and integrated assessments needed for the development of this model were fundamental for the interdisciplinary scenario design methods that were applied for the conceptual design of the ecological scenario's storyline.

Chapter five covers the design and development process for a land use scenario based on the integration of multidisciplinary assessments and iterative scenario refinement with repeated stakeholder inclusion. This chapter can serve as guideline for future projects that try to implement scenario design procedures based on the combination of social sciences, economics, ecology and landscape planning.

The acceptance and comprehensibility of computer based 3D visualization models for the communication of possible future land use scenarios has been tested in chapter six. Two alternative scenarios, closely linked to the ones presented in chapter four and five have been visualized and compared to the status quo, with questionnaires and guided interviews covering the acceptability and adaptability of such techniques for professionals from various fields of nature conservation. This thesis is concluded with a general and consolidative discussion on the main findings in chapter seven.

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2. How Do „Renewable Products“ Impact Biodiversity and Ecosystem Services – The Example of Natural Rubber in China

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Outline and overview

In order to highlight the importance, impact and relevance of the research topic, an overview of the agronomical and ecological aspects of rubber cultivation is given. Literature sources referring to the impact of different cultivation systems on natural biodiversity are discussed and an introduction to the effect of rubber cultivation on ecosystem services is given. In the second part of chapter two, a method of extrapolating the regionally adapted carbon capture properties of rubber cultivation under suboptimal growth conditions is presented and a comparative assessment is made on the establishment of rubber plantations in regard to the preexisting vegetation. Identifying some of the major challenges for nature protection in the context of the rapid expansion of rubber cultivation is one of the goals of this chapter, as well as presenting some possible (and rarely used) alternatives to the common replacement of forest ecosystems by plantation farming.

How Do „Renewable Products" Impact Biodiversity and Ecosystem Services – The Example of Natural Rubber in China

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Abstract
This paper aims to present the implications brought by the expansion of "renewable products" plantation systems in the tropics with cultivation of rubber (*Hevea brasiliensis*) as a main focus. Throughout South East Asia, natural forest is being replaced by rubber or oil palm (*Elaeis guineensis*) plantations, with severe consequences for the local flora and fauna. Main aspects of this review are: i) The provision of an overview over renewable resources in general and rubber in particular, with eco-physiological and agronomical information concerning rubber cultivation. ii) The effect of rubber plantations on biodiversity and species composition under different rubber farming approaches. In addition we debate the possible influences of such large scale land cover transformations on ecosystem services. iii) The conversion of natural forests into rubber plantations releases considerable amounts of carbon dioxide into the atmosphere. We estimated these values for different land cover types in southern China and assessed the carbon sequestration potential of local rubber plantations.

Keywords: biodiversity, renewable products, rubber, ecosystem services, carbon sequestration, ecophysiology

2.1 Introduction

Ever since, mankind has been dependent on natural resources. From the timber used to build houses to the materials for clothing or the construction of tools, most of these were renewable products obtained from the direct environment. These days, with fossil fuels and minerals to be on the decline, the large scale use of renewable resources is given an increasing degree of importance for a fast-growing human population.

The natural forests of the humid tropics are particularly rich in flora and fauna forming several hotspots of biodiversity. In South East Asia's forests, deforestation rates are highest, mainly because of an increasing agricultural expansion in order to meet the economic and nutritional needs of a growing population. Two of the main contributors are rubber and oil palm plantations. The bulk of rubber plantations in the Greater Mekong Subregion replace primary and secondary natural forest, threatening the unique wildlife and disturbing ecosystem services.

In this article, we highlight the possible impacts of large scale use of renewable products with the example of rubber cultivation in South East Asia, especially in southern China. Of particular interest are the implications of the replacement of tropical rainforest by rubber plantations concerning biodiversity, ecosystem services and carbon sequestration potential.

2.1.1 Renewable Products

The world demand for renewable resources is constantly growing because of an increasing need by a rising human population. Renewable resources are defined as materials produced by living organisms (plants, animals, microbes) used for purposes other than food and feed. Such materials include timber, natural fibre, oil and grease, sugar, starch, natural rubber, colorants, pharmaceuticals, and others containing special substances like resin, tannin, wax and/or natural protective compounds against pests and diseases (Tab. 2.1).

Table 2.1 overview over selected tropical plants for industrial and energetic use

Selected tropical plants for industrial and energetic use		
Plant	**Raw material**	**Final product**
Tectona grandis (Teak) *Swietenia* spp. (Mahogany) *Shorea laevis* (Yellow Balau)	timber	construction wood, furniture, toy, veneer, paper
Agave spp. (Sisal) *Gossypium* spp. (Cotton) *Corchorus* spp. (Jute)	natural fibre	textile, packaging material, carpet, yarn, rope, sack, paper
Elaeis guineensis (Oilpalm) *Butyrospermum parkii* (Shea nut) *Ricinus communis* (Castor oil)	oil	cosmetics, pharmaceuticals, hydraulic fluid, detergent, biodiesel
Saccharum officinalis (Sugarcane) *Siraitia grosvenorii* (Arhat fruit)	sugar	ethanol fuel pharmaceuticals, cosmetics
Manihot esculenta (Cassava) *Dioscorea* spp. (Yam)	starch	ethanol fuel pharmaceuticals, detergent,
Hevea brasiliensis (Rubber) *Parthenium argentatum* (Guayule) *Manilkara bidentata* (Balata)	natural rubber	tyre, condom, mattress, rubber profile, conveyor belt

Bixa orellana (Annatto) *Lawsonia inermis* (Henna)	colouring	colour, dyeing of leather, hair, fingernails, etc.
Cinchona sp. (Quinine) *Rauvolfia serpentine* (Indian Snakeroot) *Zingiber zerumbet* (Ginger)	bioactive chemicals	pharmaceuticals

The cultivation of these renewable resources can contribute substantially to the improvement of a local and regional economic situation but it can also result in biodiversity loss and environmental degradation.

2.1.2 Natural rubber as a renewable resource

Natural rubber extracted from the tree *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. distinguishes itself from all other raw materials, for it is elastic and at the same time reversible and hence inimitable. To gain rubber the bark of the rubber tree is cut so as to collect the latex, a milky sap from the latex vessels localised in the inner bark. Latex is an emulsion that contains e.g. water, proteins, resins, tannins, and rubber in varying quantities. The Mayas called the tree “Caa-o-chu”, that means “weeping tree” (Tab 2.2).

Table 2.2 overview over agronomic characteristics of rubber

Characteristics of the rubber tree	
name:	natural rubber
scientific name:	*Hevea brasiliensis* (Willd. Ex A. Juss.) Muell. Arg.
family:	Euphorbiaceae
habitus:	tree (may reach heights of more than 20 m within a forest)
fertilisation:	mainly allogamy by small insects such as midges and thrips, autogamy occurs to various degrees
centre of origin:	Amazon basin in South America
natural range:	humid tropics
propagation:	vegetative
first harvest:	5 – 7 years after planting
economic life span:	about 30 years
production unit:	plantation / family farming
predominant constituent harvested:	latex, timber
actual yield of dry rubber:	~3 – 4.5 kg tree^{-1} year^{-1}
potential yield of dry rubber:	about 8.5 kg tree^{-1} yr^{-1} (Ong et al. 1994)
major disease:	South American leaf blight of rubber (*Microcyclus ulei* (Henn.) Arx

Not until industrialization, natural rubber became a basic material. Nowadays, it provides the basis for many high-performance products which we come across in cars, trains, airplanes and ships, in engines and industrial plants. Wherever elastic motion is required and where it is essential to seal, convey, mount, insulate, transmit power or to damp vibration, rubber is of importance.

2.2 Ecophysiology of Natural Rubber

Hevea brasiliensis is a tropical tree. It grows best at temperatures of 20 – 28°C with a well distributed annual precipitation of 180 – 200 cm. Traditionally, *H. brasiliensis* has been cropped in the equatorial zone between 10°N and 10°S. Urged by a growing world demand rubber has now spread successfully to the latitudes 23°N (China) and 21°S (Brazil) and is cultivated up to 1200 m above sea level (Tab. 2.3).

Table 2.3 ecophysiological and climatic characteristics of tree

Characteristics for suitable cultivation of *Hevea brasiliensis*			
	Minimum	**Optimum**	**Maximum**
mean temperature (°c)	<20	25 – 28	34
mean precipitation (cm)	<150	200 – 250	400
rainy season (months)	9	11 – 12	-
moisture deficits (months)	-	0	>3
sunshine (hours d^{-1})	3	6	>7
water logging	-	none	3 days
rooting depth (cm)	>50	>150	-
pH	<3.5	4 – 5	>6
soil carbon (%)	>0.5	>2.5	-
soil fertility	low	very high	-

Today, natural rubber provides about 40% of the world rubber demand and is used in the manufacture of over 40,000 products (Ray 2004). Synthetic rubber, invented at the beginning of the 20th century, covers about 60 % of the current consumption. The world production of natural rubber is constantly growing from about 2 million tons in the 1960s to more than 10 million tons in 2007 (FAO 2008) (Fig. 1.1).

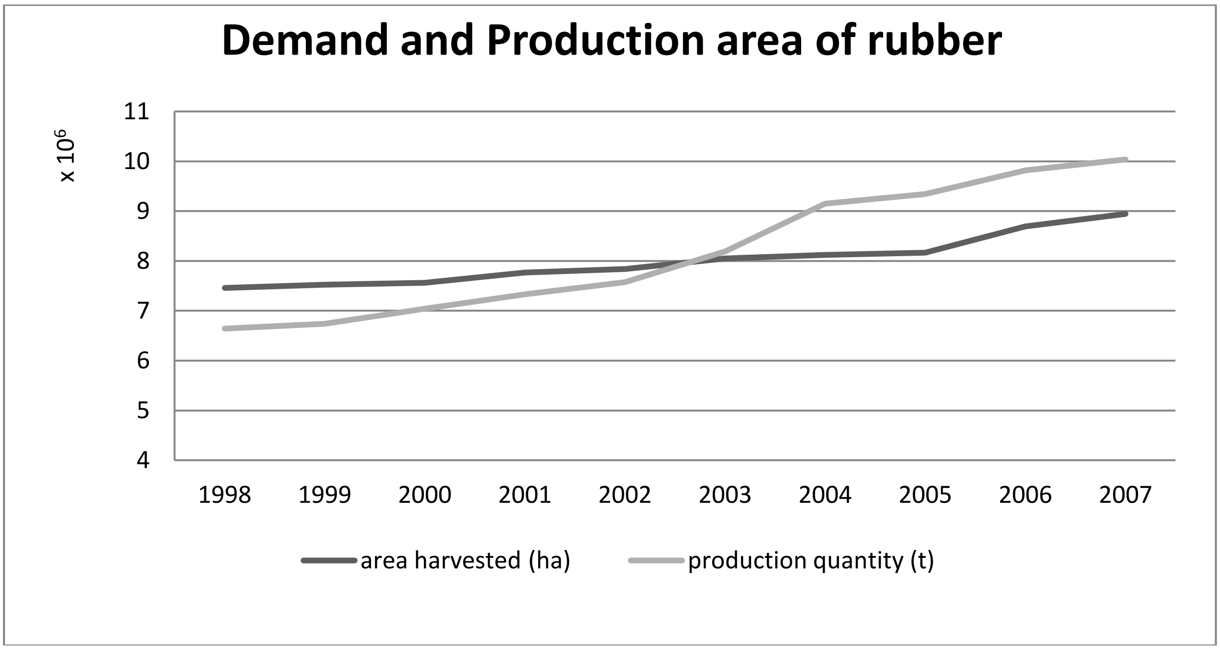

Fig. 2.1 Demand for natural rubber and area of cultivation worldwide
(*Source: FAOSTAT 2008*)

In its centre of origin, the Amazon basin, *Hevea brasiliensis* is consistently endangered by the fungus *Microcyclus ulei* (South American leaf blight of rubber). The pathogen so far inhibits plantation growth of rubber trees in South America (Lieberei 2007). Beneficiaries of this situation are located in South East Asia where the fungus has not spread to date. Thailand, Indonesia and Malaysia are the main rubber producers followed by Viet Nam and China (FAO 2008) (Tab. 2.4).

Tab. 2.4 overview over the main rubber producing countries and their area of rubber cultivation, average yield and total production quantity. Data from FAO.

Major natural rubber producers of the world (data of 2007)			
Country	Area harvested (1000 ha)	Yield (t ha^{-1})	Production quantity (1000 t)
China	475	1,1	545
Indonesia	3175	0,8	2540
Malaysia	1400	0,9	1270
Thailand	1763	1,7	3122
Viet Nam	512	1,0	550

Microcyclus ulei remains the Achilles' heel of natural rubber production. Not only that its introduction to South East Asia would cause an economic loss to the producers but it would precipitate a crisis within the many industries (medical, transportation, defence, etc.) which are dependent on natural rubber in the manufacturing of their commodities.

2.3 Rubber production systems and the conservation of natural biodiversity

Natural forest vegetation in the humid tropics is dwindling in an alarming rate, and the loss of biodiversity due to the decline of such habitats is a well-known fact. The level of deforestation in SE-Asia is the highest among tropical areas (Sodhi et al. 2004). The major reason for this is the increasing agricultural expansion, especially due to oil palm and rubber cultivation.

The expansion of rubber plantations in SE-Asia largely takes place by the reduction of primary and secondary natural forest areas. The loss of natural forests is especially serious in the major rubber production areas of Asia, because they are located within the so called Indo-Burma hotspot, one of the 34 global biodiversity hotspots identified by Biodiversity Hotspots (2007). This region largely corresponds with the Lower Mekong catchment area and also includes parts of southern and western Yunnan as well as southern Chinese offshore islands such as Hainan.

The replacement of any type of forest by a rubber monoculture results in a reduction of natural tree species diversity to zero, because the rubber tree is not even native to that region. Many studies also confirm significant reductions of fauna in plantations compared to natural forest. For example, Danielsen and Heegaard (1995) found that conversion of primary forest to rubber and oil palm in Sumatra led to simple, species-poor and less diverse animal communities with fewer specialized species and fewer species of importance to conservation. In the plantations, only 5-10% of the primary-forest bird species were recorded. Primates, squirrels and tree-shrews disappeared except for one species. Similarly, Peh et al. (2005) found reductions in primary-forest species of more than 70% in such habitat types in Malaysia.

There are two approaches to reduce biodiversity losses in rubber and other types of monoculture plantations. The first is the diversification in terms of plant species richness and vegetation structure of the plantation itself, and the other is the preservation of landscape diversity, specifically the maintenance of natural forest patches within plantation areas.

Diversification of rubber plantations is realized in a variety of cropping systems. From southern Yunnan (China), Wu et al. (2001) classified the existing rubber plantations into four types. These are

a) monoculture rubber, representing the most common type,
b) temporarily intercropped rubber plantations, with annual crops (e.g. upland rice, corn pineapple, passionflower) established between young rubber trees before canopy closing,
c) rubber plantations of multiple species and layers of shrubs and perennial herbaceous plants such as tea, coffee, cardamom and vanilla, and
d) mixed rubber plantations based on the principles of traditional home garden systems with perennial plants including tea, coffee, fruit trees bamboo and bananas, which are mainly established in aging rubber plantations.

In this sequence, there is an increase in structural as well as plant diversity, but most or all of these plant species do not represent natural forest species. Although no studies on faunal diversity have been conducted in these types of plantations, it can be expected that it is still very low and do not support significant numbers in forest species. In terms of plant species diversity and structure, such polyculture systems are probably similar to the mixed-rural landscapes in Malaysia the study of Peh et al. (2005), consisting of agricultural land, oil palm, rubber and fruit tree stands.

More complex and more diversified is the so-called “jungle rubber”, “rubber garden” or “rubber agroforest” system of Indonesia, specifically Sumatra and Kalimantan. It can be defined as a balanced, diversified system derived from swidden cultivation, in which man-made forests with a high concentration of rubber trees replace fallows. Most of the income comes from rubber, complemented with temporary food and cash crops during the early years (Guyon et al. 1993). In its structure, they resemble secondary forest with wild species tolerated by the farmer.

Beukema et al. (2007) compared plant and bird diversity of the Indonesian jungle rubber agroforestry system to that of primary forest and pure rubber plantations. They found that species richness in jungle rubber was slightly higher (in terrestrial pteridophytes) similar (in birds) or lower (in epiphytes, trees and vascular plants as a whole) than in primary forest. For all groups, species richness in jungle rubber was generally higher than in rubber plantations. The authors conclude that the jungle rubber system does support species diversity in an impoverished landscape increasingly dominated by monoculture plantations. From a more specific study on terrestrial pteridophytes (ferns and fern allies) in jungle rubber and primary forest, Beukema and Noordwijk (2004) conclude that jungle rubber systems can play a role in conservation of part of the primary rain forest species, especially in areas where primary forest has already disappeared.

Of economic reasons, however, the most common type of rubber cultivation is the monoculture system. In such landscapes, natural biodiversity can only be conserved in remaining plots of natural vegetation, which should be preserved as reservation areas. Several aspects of this approach needed to be considered for practical implementations (Debinski et al. 2001):

a) The frequency and spatial distribution of habitat fragments and patches determines species distribution patterns.
b) Species populations may be separated on patches of their habitat within a landscape of less suitable habitat, and
c) Species dispersal patterns may interact with patch size and patch context to determine species distributions within and among patches (“patch context” describes the habitat type adjacent to a patch)

Derived from this, a concept for measuring landscape structure has been developed, named “landscape connectivity” (as discussed in e.g. Merriam 1991). It describes the degree to which the landscape facilitates or impedes movement of species populations among habitat or resource patches. An important question related to this is whether the size and structure of the landscape matrix acts as a corridor or barrier between patches.

All these points also apply to forest patches within monoculture rubber plantations. However, no study dealing with matrix effects on species movements in such landscapes has been conducted so far. Specifically, there is no information on the arthropod diversity of rubber plantations in comparison to forests. In order to develop species conservation concepts in rubber dominated landscapes, research needs to address this question.

2.4 Ecosystem Services

Ranging from the provision of clean drinking water to the pollination of fruit crops, mankind is deriving benefits from a wide array of processes and interactions that take place in our environment. These services are vital to the functioning of our ecosystems, and vital to the livelihood of men, as they provide not only the basis for human life, but also additional attendances like food and health security or cultural and spiritual values. The total amount of these services can only be estimated, but cautious predictions state a yearly value of 33 trillion (10^{12}) US$ (Costanza et al. 1997, Eamus et al. 2005).

Generally, ecosystem services can be grouped into four categories. (1) Provisioning services that include goods taken from the ecosystem like food, fiber, fuel, genetic resources, fresh water and biochemicals. (2) Regulating services take place on a more global scale; they include climate regulation, pest and disease regulation, natural hazard protection, water purification. (3) Cultural services include recreation and aesthetic values, knowledge system, spiritual and religious values. (4) Supporting services comprise soil formation and retention, provision of habitat, primary production, water and nutrient cycling (Millennium Ecosystem Assessment, 2005).

Ecosystem goods and services are in danger as the human impact on the environment is constantly increasing (IPCC, 2007). Deforestation and the increase of agricultural areas, water pollution and rising fresh water demand, degradation and unsustainable use have put many ecosystems on the brink of collapse.

2.4.1 Impacts of rubber cultivation on ecosystem services

In South-East Asia large areas of natural vegetation with their plentiful diversity of flora and fauna have been put under great pressure from the establishment of plantations. Rubber is playing a great role in this process, as the anticipated revenues are appealing to farmers and policy makers alike. In China's Yunnan province, more than 11% of the total area is covered with rubber (Li et al. 2007), but there are townships where rubber cultivation contributes to more than 45% of the land cover (Hu et al. 2007). For one of these townships, Menglun, Hu et al. (2007) estimated the value of ecosystem services provided. According to this report covering land use change over a period of 18 years, the total value of ecosystem services dropped by US$ 11.4 million (28%). The services most affected were nutrient cycling, erosion control and climate regulation. The biodiversity service of "habitat/refugia" had not been covered, but considering the detrimental effect of monoculture plantation systems on species richness and the corresponding ecosystem services, the total value of ecosystem services for the research area can be expected to be even lower than reported. This effect seems to be alleviated by the fact that the townships gross domestic product increased, leading to a ratio of 1:1.39 for increase in GDP to loss of ecosystem services in US$ (Hu et al. 2007).

2.4.2 Deforestation due to rubber expansion

The increasing demand for natural rubber products has lead to a widespread replacement of natural forest vegetation with rubber. Li et al. (2007) states that between 1976 and 2003 tropical seasonal rainforest in Yunnan was reduced by 67%, mainly due to the planting of rubber. Lowland rainforests are the most affected forest types due to the climatic needs of the rubber tree. But also mountain rainforests and other forest communities of higher elevations are seriously under pressure, as agricultural production shifts into these regions.

According to the recommendations given by the International Panel on Climate Change (IPCC, 1997) as used by Germer and Sauerborn (2008), we assessed the potential amounts of carbon and carbon dioxide emission that are expected when preparing land for the conversion into rubber plantations. Again, the data from the Yunnan Institute of Forest Inventory and Planning (Li et al. 2008) served as a basis for our biomass assumptions. As basis for the distribution of below to above ground biomass, we used a BGB to AGB ratio of 1:1.13 as given by the IPCC (1997).

For the emission of CO_2 during decomposition, we assume that after 30 years under humid subtropical conditions, all cleared biomass, above and below ground, will be decomposed. IPCC (1997) suggests a vegetation independent forest carbon stock estimate of 50% of the biomass. Carbon (12 g/mol) will mostly be released as carbon dioxide (44 g/mol). One ton of cut forest biomass would release 0.5 t of carbon through decomposition, resulting in the emission of 1.8 t CO_2.

As an example, the average carbon content of one hectare of undisturbed tropical seasonal rainforest in Yunnan was reported to be 121.74 t, which is an estimated 243.5 t of biomass, assuming a forest stock carbon content of 50% (IPCC 1997). The complete decomposition of this amount would lead to the emission of (243.5 t x 1.8) = 438.3 t CO_2.

Tab. 2.5 expected Carbon-dioxide emission from the clearing of different forest types. TSRF: tropical seasonal rainforest; SEBF: subtropical evergreen broadleaf forest (57% of Yunnan forests); TSRF anth., SEBF anth. both with strong anthropogenic influences (e.g. selective logging); Grass: grassland, Shrub: shrubland. Carbon content values from Li et al. (2008), other values calculated following IPCC guidelines.

Emission of CO_2 equivalents by forest clearing			
	Carbon content t ha^{-1}	**Above ground biomass t ha^{-1}**	**CO_2 emissions decomp. t ha^{-1}**
TSRF	121.74	212	438
TSRF anth.	75.17	131	271
SEBF	105.24	183	379
SEBF anth.	71	124	256
Grass	5.32	4.4	19.2
Shrub	14.56	25.3	52.4

2.5 Carbon sequestration potential of rubber

Properly managed rubber plantations that are supplied with sufficient amounts of fertilizer have a high potential to act as a continuous sink for atmospheric carbon dioxide (Cheng et al. 2007). This is mainly due to their high sequestration rates and the fact that there is a constant export out of the production system by means of tapping.

Cheng et al. (2007) reported a 30 years lifetime carbon sequestration of 272 t C ha^{-1} in rubber plantations on the island of Hainan. Comparing this to the sequestration rates of rainforests and secondary forests on Hainan, 234 and 150 t C ha^{-1} over the same period, the high productivity of a rubber plantation becomes discernable. Nevertheless, more than 57% of the sequestrated carbon ends up in easily decomposed litter. This decomposition process returns considerable amounts of carbon back to the atmosphere, up to fifty percent of the total carbon content in the first year

(Anderson and Swift, 1983).

Based on the equation used by Cheng et al. (2006), we were able to derive carbon sequestration values for rubber plantations (C_R) in Yunnan province, China's second biggest rubber producer. We can calculate C_R as:

$$C_R = C_{Bi} + C_{La} + C_{Li}$$

Data from the Yunnan Institute of Forest Inventory and Planning published by Li et al. (2008) were used to obtain information about local forest biomass and its carbon content (C_{Bi} = 61.48 t C ha^{-1} for rubber plantations below 800m).

The amount of sequestrated carbon that is removed from the field during latex tapping was estimated by multiplying average values of latex carbon content by latex yield per hectare (FAOSTAT 2007) by the economic lifetime of a rubber plantation in years (C_{La}). Due to suboptimal climate conditions rubber tapping in Yunnan usually begins seven years after establishment of the plantation, in comparison to an average of five years reported for Hainan. This results in a slightly lower average economic lifetime. In order to estimate the amount of litter produced over 30 years we proportionally adjusted the values for Hainan litter biomass per hectare to the lower total biomass of Yunnan rubber plantations (C_{Li}).

Based on these calculations, the estimated carbon sequestration during a 30 years lifetime for rubber plantations below 800m elevation in Yunnan province is 192 t C ha^{-1}, which consists of an estimated litter mass of 107 t C ha^{-1} and a latex output of 23 t C ha^{-1}.

These estimates do not consider the soils potential to release and sequestrate carbon under different management regimes. In this context, the dynamics of carbon cycling regarding the substantial amounts of litter produced by rubber plantations should be put to further investigation, as these results could lead to a clearer picture of the overall carbon sequestration potential of rubber.

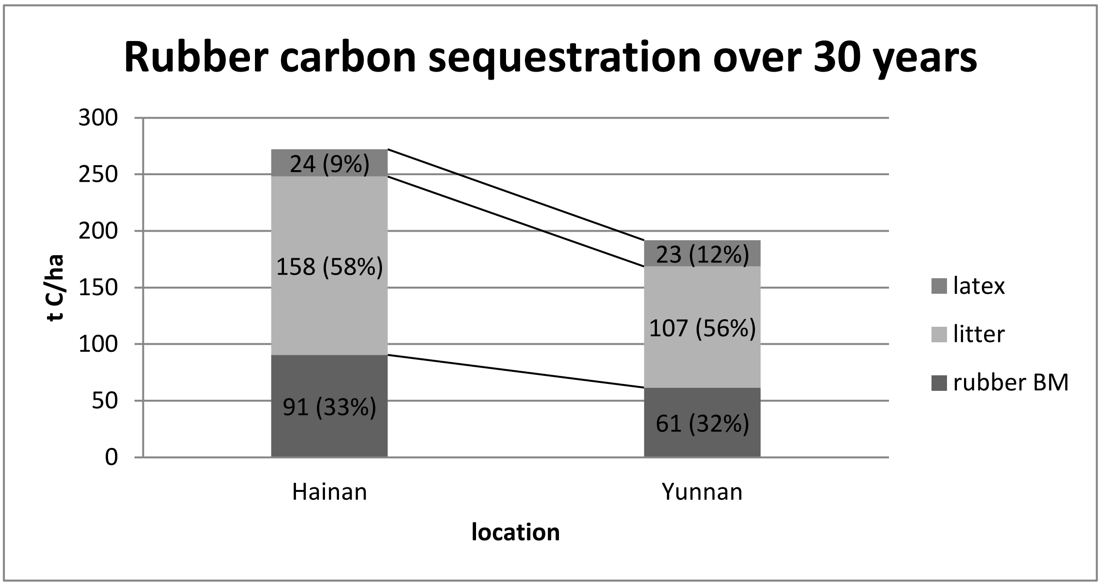

Figure 2.2 Total carbon sequestration by rubber over 30 years per hectare. Total values are divided into latex production, litter production and rubber biomass (non-litter)

2.5.1 CO_2 balance in plantation establishment

During its lifetime of 30 years, a rubber plantation in Yunnan province can sequester an estimated 192 t of carbon or 703 t CO_2 per hectare (based on an atomic weight ratio of 1:3.66). Plantations in Hainan province can be expected to achieve about 272 t of C sequestration, mostly due to their higher biomass and litter production. These values are, as stated above, comparable to the 30 years sequestration potential of Hainan rainforests.

When comparing these vegetation types concerning their CO_2 balance, one decisive fact has to be considered. Rubber plantations are man-made ecosystems which replace local floral communities entirely. In most cases, this is done by clearing the forest for the plantation establishment. Based on our estimates, if one hectare of relatively undisturbed tropical seasonal rainforest in Yunnan province is cleared, this process releases about 438 t of CO_2 into the atmosphere. A fully grown rubber plantation on the same spot would need around 20 years to re-sequester this amount of CO_2. Although after several decades a net gain in carbon fixation could be achieved, the loss in biodiversity and ecosystem resources would be persistent.

Tab. 2.6 Carbon sequestration rates per hectare over 30 years and annual average. Data for Hainan were published by Cheng et al. (2007); values for Yunnan Rainforest and Secondary forest were derived proportionally from Hainan sequestration rates and Yunnan biomass values.

Carbon sequestration over 30 years and annually			
	Rubber	**Rainforest**	**Secondary**
C_{seq}30 ha^{-1}Hainan	272 t	234 t	150 t
av. C_{seq} a^{-1} ha^{-1}	9.1 t	7.8 t	5.0 t
C_{seq}30 ha^{-1}Yunnan	192 t	165 t est.	106 t est.
av. C_{seq} a^{-1} ha^{-1}	6.4 t	5.5 t est.	3.3 t est.

2.5.2 Rubber and grassland rehabilitation

In order to find more sustainable locations for the establishment of rubber plantations disturbed ecosystems like degraded grassland and abandoned fallows from swidden agriculture could be used. These land uses are rather scarce in the elevation levels that are suitable for rubber plantation in Yunnan province, but nevertheless it is a promising concept for other regions nearby. All throughout the tropics and subtropics, the transformation of agricultural areas to grassland ecosystems is a common problem. These areas are often dominated by very competitive grass species that effectively prevent natural succession into secondary woodlands and forests. The conversion of these land use types into rubber plantations would not only increase the farmers' welfare but also secure important ecosystem services that grassland and fallows have difficulties to provide (Li et al., 2008). In addition, the establishment of plantations on these degraded areas would emit decisively less carbon dioxide than the conversion of forests. CO_2 release into the atmosphere during land preparation is estimated to amount to about 110 t ha^{-1} for shrubland in Yunnan, and 19 t ha^{-1} for grassland, in comparison to the 438 t ha^{-1} for Yunnan seasonal rainforest. Compared to the values reported above, this would lead to a faster and significantly higher net gain in CO_2 sequestration by rubber plantations when used to rehabilitate grassland. Similar results have been published for oil palm plantations (Germer and Sauerborn 2008).

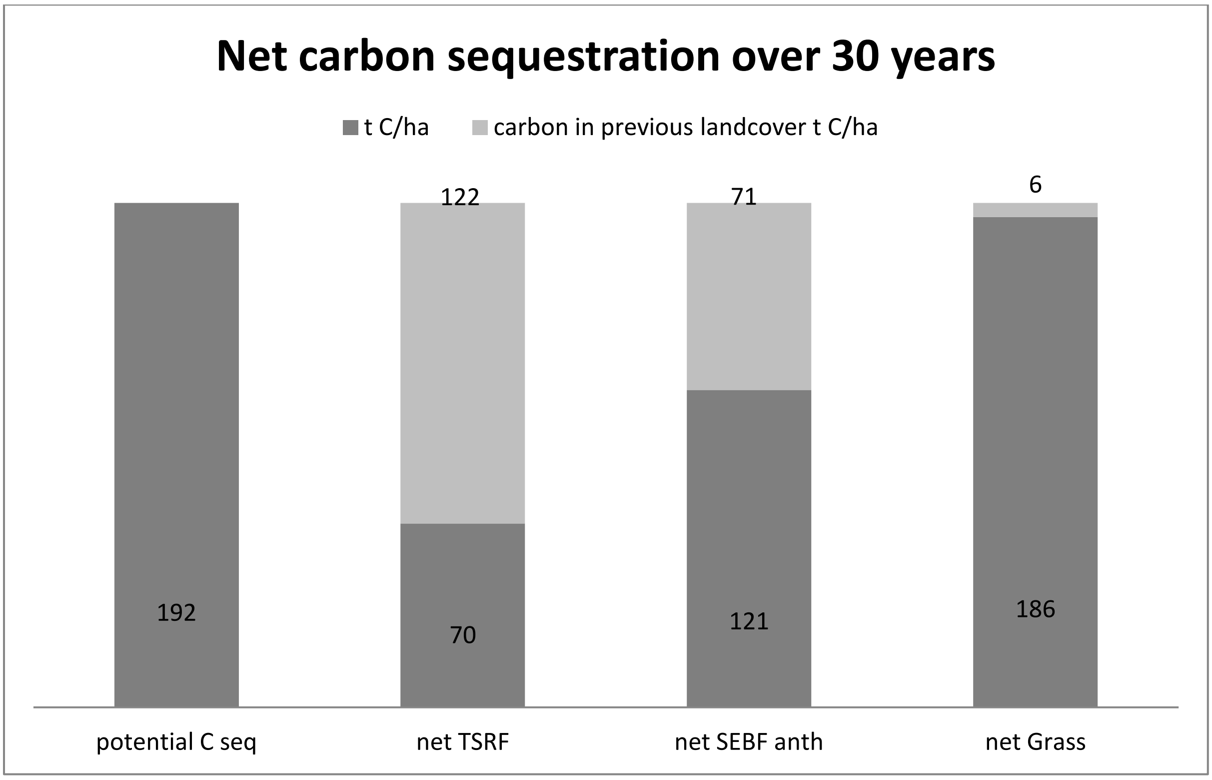

Figure 2.3 Carbon sequestration by rubber grown below 800 m a.s.l. over a period of 30 years in Yunnan province, compared to net carbon sequestration considering the release of CO_2 during plantation establishment. C seq. is the estimated carbon sequestration potential of rubber (above);
previous land cover: TSRF is tropical seasonal rainforest, SEBF anth is subtropical evergreen broadleaf forest with anthropogenic influence and Grass is grassland.

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Outline and overview

As a short introduction to the interdisciplinary framework in which this study was conducted, chapter three is giving a concise overview over the pit-falls and difficulties faced when establishing an interdisciplinary model for land use change with special focus on the combination of spatially explicit remote sensing data with transect or point-based ecological as well as qualitative socio-economic data. The Living Landscapes China - LILAC project was an interdisciplinary sino-german research project that aimed at developing a strategic tool for the assessment of land use change and rural development in south-west Chinese highland areas. The model presented later in chapter four as well as the scenario design process introduced in chapter five have both been developed as part of this collaborative research endeavor integrating ecology, economy, social sciences and landscape planning.

Use of remote sensing data as basic information for applied land use change modeling

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Abstract

The objective of the LILAC ("Living Landscapes China") project is to develop a decision support tool for sustainable land use development. Study area is the Nabanhe National Nature Reserve (NNNR), located in Yunnan province of China. The modeling framework applied in the LILAC project is called NabanFrame; it follows an interdisciplinary approach integrating environmental planning, economy, ecology, and sociology. Each of the disciplines builds up an own model under the "umbrella" of the NabanFrame modeling framework.

The paper describes the development of the common data base for the LILAC project, illustrating the different data requirements of the disciplines. An essential data source for most of the disciplines is a detailed land use map, derived from IKONOS satellite imagery for the study area. The contents of the common data base have been discussed intensely in the beginning of the project. That proofs the importance of an appropriate data base for interdisciplinary projects in particular. In discussing the data base, project participants gain a common understanding of the research topic and a more detailed insight into the problems of the related disciplines. Only by allowing this initial discussion it is possible to obtain a data base that fulfils the needs of all project participants.

摘要

„生命.景观.中国"项目是为提供实现土地使用稳定持久发展为目的的一个决策性依据。项目实施地是位于中国云南省的纳版河国家级自然保护区。在此项目中运用的模式体2系称之为"纳版体系"。此体系既将环境规划，经济学，生态学以及社会学多种学科相结合整体考虑，又在此体系下建立每种学科独自的模式。

文章以项目为例阐述了基础数据，举例强调了各个学科所需的不同数据的必要性。对大多数学科来说一个重要数据来源是由IKONOS卫星图像得出的详细土使用规划图。在项目的初始阶段已集中对所需基础数据进行了讨论，这也显示了一个适当的数据库对于多学科项目的重要性。在对基础数据进行讨论时，项目参与者们不仅对于研究主题达成共识而且发现与学科相关的更加详细深入的问题。只有通过这种形式的讨论才能使数据获得成为可能，而且由此获得的数据能满足所有项目参与者的需求。

3.1 Introduction – the integrated approach of land use change modeling

In the LILAC ("Living Landscapes China") project (project duration June 2007 until August 2010) a decision support tool will be developed for the Nabanhe National Nature Reserve in Xishuangbanna with the aim of providing policy makers and stakeholders in the region with comprehensive information for sustainable land use development. The GIS-based tool shall be able to predict the economic, social and ecological effects of different land uses, within a landscape context. Several disciplines are involved in the development of the decision support tool. Environmental planning is drawn in as well as economy, ecology, and sociology. The disciplines form the sub-projects within the LILAC project, and every sub-project is developing one part of the common modeling framework, which in turn serves as an "umbrella" for the joint application of the four models. The modeling framework is called NabanFrame, as it is developed for the study area of the LILAC project, the Nabanhe National Nature Reserve (NNNR), located in Yunnan province of China (cf. section 3.2). The LILAC modeling framework consists of three phases: a pre-processing phase, the land use allocation phase, and a post-processing phase. They are shown in figure 3.1.

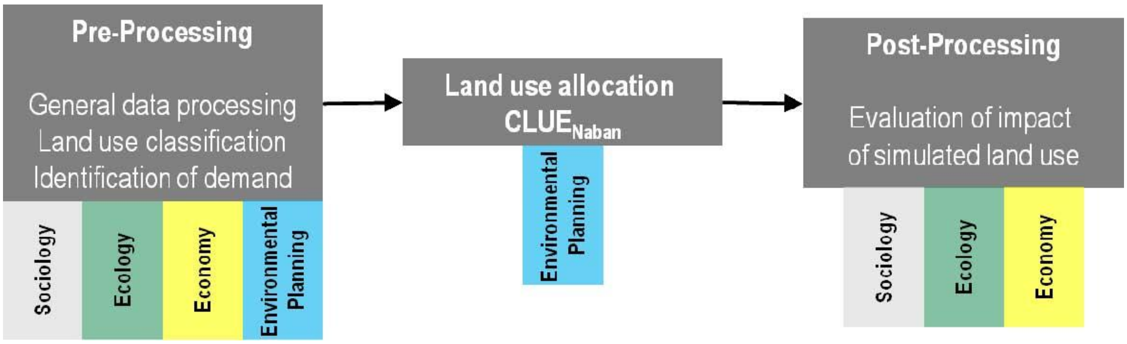

Fig. 3.1 Workflow within the NabanFrame modeling framework

In the pre-processing phase, the general data preparation takes place. The required input data are described in the following. An important data input is land use in the starting year of the simulation. It is classified from satellite imagery (cf. section 3.1). Just as important is the identification of the demands for every land use type. Depending on their objectives, the four models have different data requirements concerning content, spatial resolution, data format, and reference unit. E.g. the land use change model, "Conversion of Land Use and its effects for Nabanhe" (CLUE_Naban) relies on physical data (elevation, soil texture, precipitation) as well as on other parameters influencing land use allocation (distance to market, population density, ethnic group) (cf. Veldkamp and Fresco, 1996; Verburg et al., 1999). All these data need to be transformed to a 25 meter grid for the integration into CLUE_Naban. In contrast, the economic model works on farm type level, assigning the farms in the NNNR to six farm types developed for the region. Input data for the General Algebraic Modeling system (GAMS) based economic model are collected from interviews in the study area. Surveyed data include agricultural area, fertilizer amount, crop composition, crop rotation, and others. Table 3.1 gives an overview of the data requirements of the various disciplines in LILAC.

Table 3.1 Data requirements of the disciplines involved in NabanFrame, and further data needs within the project.

Discipline	Model	Input data	Spatial resolution	Data format	Reference unit
Environmental Planning	Land use change model (CLUE_Naban)	land use elevation soil texture precipitation distance to market population density ethnic group	25 m	Grid	Grid cell
Economy	Optimization model (GAMS- based)	land use agricultural area fertilizer amount crop composition crop rotation	Farm type	Data table (Excel)	Farm type
Ecology	Landscape metrics (FRAGSTATS)	land use elevation field surveys of flora and fauna	/	Polygon	Plot
Sociology	Social model	location of households within villages household surveys	Household	Questionnaire, data table	Household
Ecological field surveys	ECOL-B	topographic map	Varying	Data table	plot
Household interviews	/	village maps	/	/	/

It can be clearly seen from table 3.1 that the data requirements of the disciplines are quite heterogeneous. In addition to the data needs of the four models, basic data have to be provided for the preparation and realization of ecological field surveys and interviews in the villages. In section 3.4 the procedure is described which was chosen to satisfy these data needs. In the second phase of NabanFrame, the allocation of land use changes is conducted by the land use change model, CLUE_Naban, with data input from all other models. Finally, in the post processing phase, the simulated land use maps are evaluated regarding their impact on social factors, ecology (biodiversity), and economy.

3.2 Study area: Nabanhe National Nature Reserve (Xishuangbanna)

The NNNR covers an area of 264 square kilometers; it is formed by the catchment of the Naban River, which is a tributary to the Mekong River. The Mekong River outlines the eastern boundary of the catchment, as can be taken from figure 3.2.

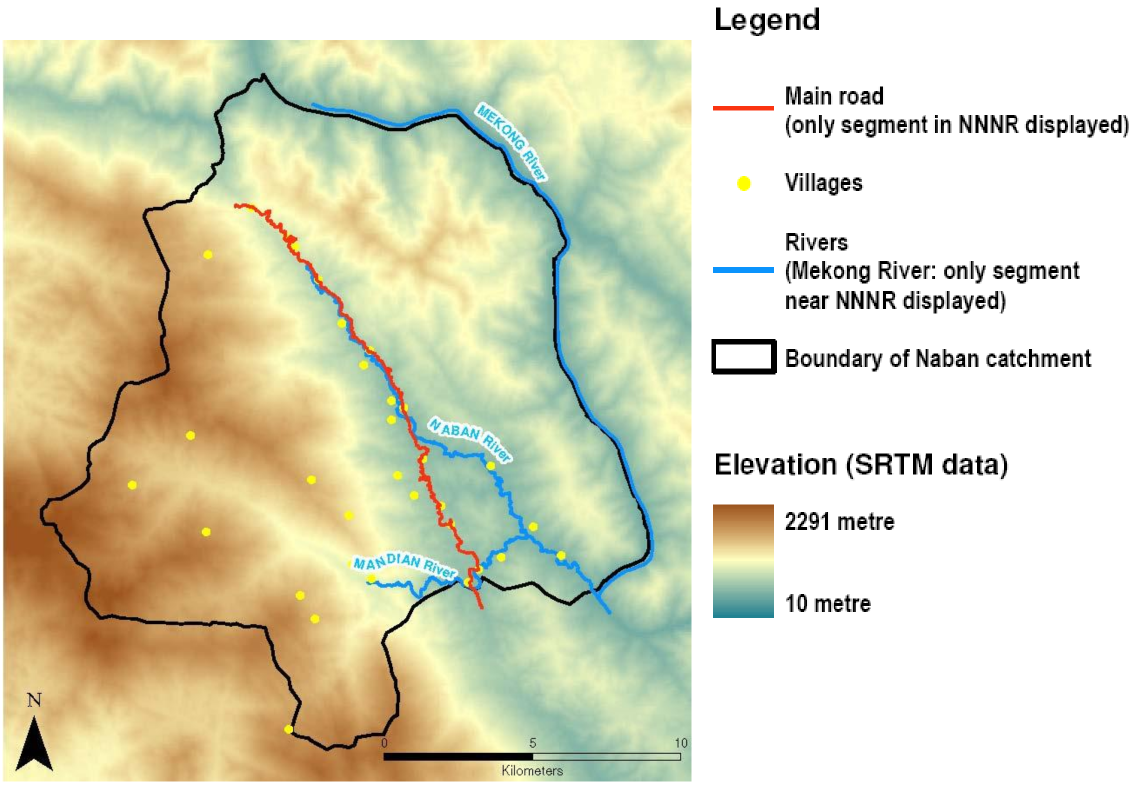

Fig. 3.2 The Nabanhe National Nature Reserve, Yunnan Province, PR China, topographic detail derived from SRTM data

The study area is located 20 kilometers north-west of Jinghong city in Xishuangbanna province of Yunnan. The NNNR belongs to the subtropics, the regional climate being heavily influenced by the southwest monsoon with intense rainfalls from May to October. Elevation in the areas ranges from 510 to 2291 meters; the highest elevations can be found in the western part of the study area.

3.3 Data sources

Several data sources are available to satisfy the data needs described in table 3.1. They can be divided into satellite data and household surveys, and will be described in the following.

3.3.1 Satellite data

Like in other rural and remote areas, also in the NNNR no information on land use types was available for the whole of the area. Satellite imagery provides an opportunity to overcome this lack of data, since it provides area-wide land use information. A basic land use map of the NNNR for the year 2007 is required by most of the disciplines. As particularly the ecological subproject needs a very detailed land use map, it was decided to use IKONOS imagery to classify land use. Information gaps due to cloud cover in the IKONOS image were filled with the help of SPOT 5 data. Additionally, LANDSAT-3/4/7 satellite images of the years 1980, 1989 and 2001 (U.S. Geological Survey, 2007) were classified to define trajectories of land use change, which are necessary for the land use change model.

3.3.2 Household surveys

Household surveys in the NNNR villages were conducted by a number of PhD students with the collaboration of Chinese translators. From March 2008 to July 2008, 219 households were interviewed, focusing on different topics depending on the sub-projects. Interviews were conducted from both the economy and the sociology sub-projects. Interview results were evaluated qualitatively. It was necessary to built up a common data table within the LILAC project, which contains unique ID numbers for the surveyed households as well as the village they belong to and some basic information about the persons who were interviewed. This data table is updated continuously and thus serves the purpose of coordinating the interview activities in the villages (to avoid double interviews or interview "accumulation" in single villages). Table 3.2 shows the structure of the Household ID data table.

Table 3.2 Content of the Household ID data table of the NNNR

V-ID	V_NAME	ADM_V	TWNSHP	HSE_ID	HSE_NMEP	HSE_NMEC	GND	INTVW	DATE
Village ID	Name of village	Administrative village	Township	Household number	Name in Pinyin	Name in Chinese	Gender	Interviewer	Interview date

3.4 Data processing

Data processing in the beginning concentrated on the development of a detailed land use map, as this is a basic data input for most of the sub-projects. As mentioned above, the land use map was derived from IKONOS imagery. Six IKONOS 2 scenes were available (European Space Imaging, 2008); three of them were selected to represent the whole of the NNNR. Georeference correction was necessary, because the images only were available in product level "Geo", i.e. without ortho-correction, and not mosaicked. The correction was done using Global Positioning System (GPS) measurements taken in the area. The three images then were mosaicked. After that, areas of interest were defined (using ENVI 4.4) for all land use classes. For that reason, ground truth data were collected during field studies within the NNNR. Further, ecological experts made land use classifications based on visual on-screen interpretation of IKONOS images. With the help of the defined areas of interest, a supervised classification was prepared in the ENVI program. It resulted in the classification of 9 land use classes:

1. paddy rice
2. farmland
3. forest
4. rubber
5. bamboo
6. grassland
7.water
8. stream bank
9. cloud shadow/ not classified

The post-processing of the classified image was done in ArcGIS 9.2, using the majority and the boundary clean function. Within the post-processing process, a tenth land use class, "settlement area", has been added. Information gaps due to cloud cover in the IKONOS image were filled with the help of SPOT 5 data (SPOT Image, 2007) (supervised classification as well).

IKONOS satellite images turned out to be the most important data source for the LILAC project, because they helped to fulfill also the following data requests (besides land use classification):

Location of households within villages

Topographic map of study area

Village maps

The sociological sub-project digitizes household locations from the IKONOS image to add spatial reference to their data. Details of the IKONOS image also were printed out as “village maps” for the spatial allocation of households during interview trips. Figure 3.3 shows such a village map. A topographic map has been created from the IKONOS image (digitized villages, roads, rivers), which is absolutely necessary for the planning and conduction of field trips.

It can be stated that IKONOS imagery is particularly useful in interdisciplinary projects, wherein not all participants are familiar with remote sensing data. IKONOS images can be understood easily because of their high resolution and their similarity to aerial images.

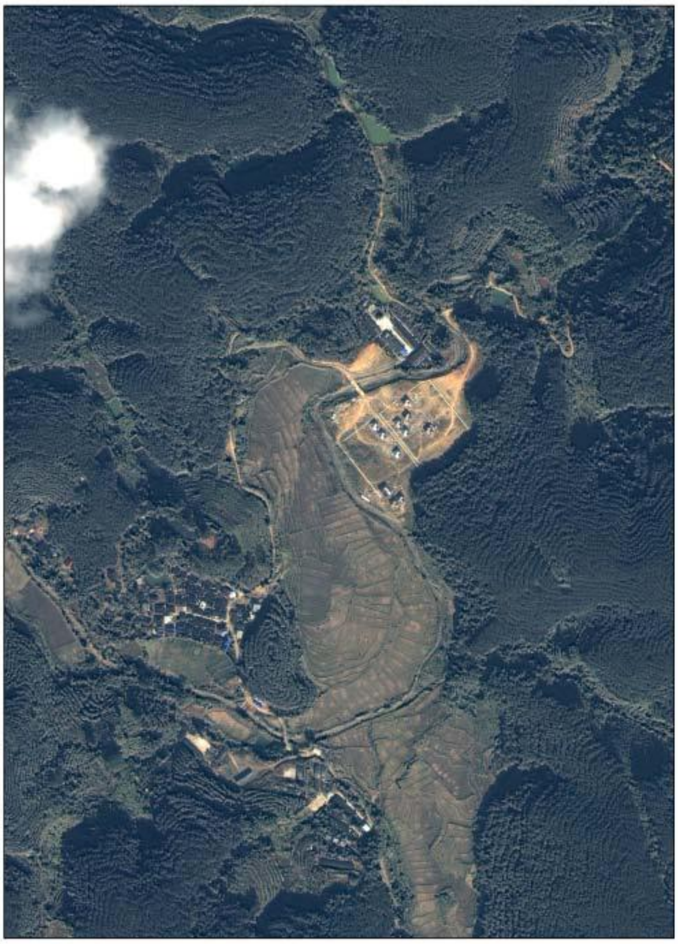

Fig. 3.3 Detail from IKONOS satellite, showing Mandian village in the rubber growing lowlands of NRWNNR (European Space Imaging, 2008)

Summarizing the data processing procedure, a common data base for the LILAC project has been created (in the form of an ArcGIS Geodatabase), which integrates the needs of all subprojects. Its content is presented in table 3.3.

Table 3.3 Common data base of the LILAC project (data in brackets are not yet available or not yet implemented)

Feature/grid file	Attributes	Spatial resolution	Source
IKONOS mosaic	/	1m	IKONOS
Land use 2007	9 land use classes	1m	IKONOS
Land use 2001	5 land use classes	30m	Landsat
Land use 1989	5 land use classes	30m	Landsat
Land use 1980	5 land use classes	30m	Landsat
Villages	Household IDs	/	IKONOS
Roads	/	/	IKONOS
Rivers	/	/	IKONOS
Digital elevation model	Elevation	90m	SRTM
(Digital elevation model)	Elevation	1.25m	TerraSAR-X
(Precipitation)	Amount of precipitation	/	Monitoring stations
(Soil texture)	Soil texture	/	Soil survey

3.5 Data provision

A number of project partners in Germany as well as in China are involved in the LILAC project. That makes it necessary to provide data in a central place, with easy access for all partners. In the LILAC project, data are distinguished between 1) Geodata and 2) Data without explicit spatial reference (e.g. interview results). Geodata are stored on a central server and can be accessed via ArcGIS Server. Additionally, they are also available on an FTP server. This is necessary, because in fact the ArcGIS Server offers multiple functions regarding the visualization and processing of geodata (even without desktop GIS installed), but does not provide access to the original data. For that reason, the original geodata are available from the FTP server. Data without explicit spatial reference are only available on the FTP server. In case they are household-related, they refer to the common household ID data table to guarantee data continuity.

3.6 Example of data base use

The common data base is used individually by the different disciplines. E.G. the IKONOS land use map is a basic input for the CLUE_Naban model (cf. Herrmann & Berkhoff 2008), the economic model, and the ecological model. In the following, it is described exemplary how the ecological sub-project makes use of the land use map which is contained in the data base.

3.6.1 Landscape Matrix analysis

Based on the IKONOS land use map, the ecological sub-project made an analysis of landscape structure in the NNNR. Software used for this investigation were ArcGIS and FRAGSTATS (McGarigal et al., 2002). The GIS facilitated transformation from the raster based land use map into an ASCII file readable by FRAGSTATS. Preliminary model runs have been conducted using parameters and estimates derived from field data. Although an extensive set of indices has been calculated during this process, the main focus in the further modeling process will be on the following set of indices:

Mean patch size and proportional abundances of the different land use classes

Contagion and interspersion indices to clarify tendencies of land use types appearing in direct proximity to the same land use

Patch density

Largest patch index

Area weighted mean patch fractal dimension

These indices are considered suitable for the comparison of different landscape matrices (Lausch & Herzog, 2002).

3.6.2 Ecological Evaluation model

In field surveys, data on biodiversity (flora and fauna, in particular insects) within the NNNR are evaluated. In order to combine the surveyed information on biodiversity a framework concept has been established. The data on fauna and flora will be combined into different indices using benchmarking processes. These indices will be normalized with the highest value of the corresponding data set. Some of these combined indices will be species diversity, abundance or the occurrence of rare and endangered species. After normalization, the variables will be directly linked to the corresponding classes in the IKONOS land use map using a GIS. The thematic raster maps resulting from this process will be altered by using mathematical equations. They are derived from the data sets provided by the fauna migration analysis, the work on floral habitat suitability as well as extensive literature review. Special focus will be laid on barrier, corridor and halo effects (Ricketts, 2001). This process will lead to a set of rules that allows the thematic maps to be transformed into a combined categorized map of biodiversity value or ecological significance. That procedure is part of the post-processing phase of the NabanFrame modeling framework. In the post-processing phase, the evaluation of modeled land use maps takes place (cf. figure 3.1).

This example from the ecological sub-project shows how data from the common data base are used in one of the disciplines involved in the LILAC project. The contents and the structure of the LILAC data base have been discussed intensely in the beginning of the project. That shows the importance of an appropriate, useable, and accessible common data base for interdisciplinary projects in particular. In discussing the data base, project participants gain a common understanding of the research topic and a more detailed insight into the problems of the related disciplines. Only by allowing (and encouraging) this initial discussion it is possible to obtain a data base that fulfils the needs of all project participants.

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4. A biodiversity evaluation tool for the tropics – modeling concept for planning and conservation

Submitted to PLoS One, currently in review

Outline and overview

Within the framework of the LILAC project we have developed our biodiversity evaluation tool. By combining some of the findings discussed in chapter two with our research group's own ecological field work we have been able to design a methodology for up-scaling plot based data on plant species diversity and combining them with landscape metrics. This method was developed and tested with the comparative assessment of a linear extrapolation land use scenario and multiple alternative land use scenarios over the course of three years. This work is being presented in chapter four. The findings and integrated assessments needed for the development of this model were fundamental for the interdisciplinary scenario design methods that were applied for the conceptual design of the ecological scenario's storyline in chapter five.
Over the course of the research project, the methodology presented here in chapter four has been adapted slightly to fit to new findings and a continuous improvement process has lead to some changes in the composition of indices concerned with medicinal plants and red list species between chapter four and chapter five (see chapter seven, discussion, for more details).

A biodiversity evaluation tool for the tropics – modeling concept for planning and conservation

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Keywords: biodiversity indices, ecosystem services, landscape metrics, *Hevea brasiliensis*, Greater Mekong Subregion, discussion support tool

Abstract

We have developed a biodiversity evaluation tool based on the combination of approaches from landscape ecology and empirical data within a Geographic Information System. Detailed data on plant species diversity and distribution were combined with quality criteria like endemism or invasiveness to form spatially explicit biodiversity indices for different land use types in various elevation classes. Up-scaling in accordance to the land use distribution observed in a representative area, a watershed in south-western Yunnan province, PR China, allows the estimation of overall plant diversity and the evaluation of future changes and scenarios. Habitat characteristics and spatial distribution were included into the analysis of the land use map derived from remote sensing information to allow for the assessment of fragmentation and landscape matrix structure.

Similar approaches have proven useful in extending field observations in areas where topography or other factors constrain empirical analyses. Our assessment covers a multitude of land use systems and natural land cover types, including rapidly expanding lowland rubber cultivation in various stages of development.

The aim of this tool is to provide scientists and policy makers with information about the current state of biodiversity in an area or administrative region and enable them to predict the likely impacts of intended or expected land use changes on structural and ecological diversity.

4.1 Introduction

Rural development and simultaneous environment conservation often face trade-offs, especially in regions that host an exceptionally high biodiversity, as is the case in many tropical areas. Crude methods of infrastructural advance and large-scale farming can pose a great threat to endemic and rare species of flora and fauna. On the other hand, strict conservation approaches can greatly limit the rural population's scope for improving its livelihood (Lawrence 1996, UNESCO 2007, Steffan-Dewenter and others 2007). Therefore, tools and methods that allow decision makers to assess the impacts of different management and infrastructure options on the environment have to be developed. These tools must be useful also under the conditions of tropical areas and must take into consideration the particular needs of rural areas that face drastic changes concerning land use, structural development and economic stability. As biodiversity affects the livelihood of rural populations directly (e.g. through the provision of medicinal plants or food collected from the wild) and indirectly (e.g. access to clean drinking water filtered by forest soils) via a multitude of ecosystem services, the assessment of the effects of future land use possibilities and scenarios on species diversity will yield valuable information on the sustainability of regional development paths.

The research area to which our model is applied is the Naban River Watershed National Nature Reserve (NRWNNR, 22°08'N 100°41'E) in the province of Yunnan, PR China. Yunnan is part of the Indo-Burmese "hot spot of biodiversity" (Myers and others 2000), that hosts around 13500 native plant species. Xishuangbanna Prefecture supports 16% of Chinas higher plant species on only 0.2% of the national area (Zhang and Cao 1995). The nature reserve covers 271 km² and its elevation ranges from 500 m to 2300 m a.s.l., covering the watershed of the Naban River, a tributary of the Mekong river (Lancang Jiang). It features an especially high diversity of natural vegetation types, as well as a variety of land use systems due to the topographically and ethnically diverse background of the region (Zhu 2008). In Xishuangbanna, economic development and biodiversity conservation compete for the same land. So far, economic goals have dominated: from 1976 to 2003, 140'000 ha of tropical rainforest were replaced by rubber (*Hevea brasiliensis*) plantations (Li and others 2007). Since then, forest clearing has continued. In the last decades, the cultivation of rubber has rapidly gained importance in the Greater Mekong Subregion, displacing traditional land use systems like forest gardens or shifting cultivation. The expansion of rubber has caused a reduction and fragmentation of natural and near-natural forests, with all the consequences like a reduction in structure and biodiversity as well as the loss of valuable ecosystem services (Wu and others 2001, Zhu and others 2005). On the other hand, rubber cultivation is well accepted among local land users, as its introduction had remarkable impacts such as the improvement of income, infrastructural advances and enhanced access to welfare and healthcare facilities (Tang and others 2009).

Our research is based on the assumption that it is possible to reduce biodiversity loss while improving livelihoods and enhancing the socio-economic and cultural conditions for environmental sustainability, as postulated by the Man and the Biosphere (MAB) Programme of UNESCO. Xishuangbanna is a member to the MAB network since 1993.

In this paper, we present a GIS-based tool to assess the impact of land use on biodiversity on a local and regional scale. The suggested biodiversity evaluation tool is based on the assessment and comparison of selected plant community characteristics and landscape metrics. We compiled empirical field data and transferred them into spatially explicit indices for the evaluation of biodiversity at watershed level. Landscape metrics were calculated to highlight the effect of rubber plantations on natural habitat distribution and fragmentation.

The aim of this tool is to provide scientists, administration and policy makers who have to evaluate the consequences of scenarios of future land use with knowledge-based information on the current and likely future state of biodiversity in their area. This will enable them to assess the likely impacts of land use changes on structural and ecological diversity and allow for informed land use planning. Regional development or nature conservation agencies, from government or private sector, conservation and regional administration employees as well as scientists looking for a tool that combines field data with the possibility of up-scaling are the target group for the methods presented here. The structure of this tool allows the application in other areas of the world facing similar problems with expanding annual and/or perennial cropping systems.

4.2 Data collection (materials)

4.2.1 Land use

A map of the current land use was derived from IKONOS satellite imagery, acquired on November 16th and December 2nd, 2007. During field visits, ground truth was conducted and six main land use classes (LUC) were identified. A partner workgroup at the University of Hannover derived a land use map via supervised classification using ERDAS Imagine software and subsequent reclassification with additional land cover information to improve reliability. This land use map provided the spatial basis for the evaluation tool (Berkhoff and others 2009). Effects of elevation and land use policy on the spatial distribution of LUC were of particular interest. Landscape metrics are included in the analysis of the research area to allow for a quantitative comparison of landscape structure in different sub-regions of the NRWNNR, especially concerning the introduction of large-scale rubber plantations and their effect on habitat distribution and fragmentation. The main tool for this analysis was FRAGSTATS 3.0 (McGarigal and others 2002).

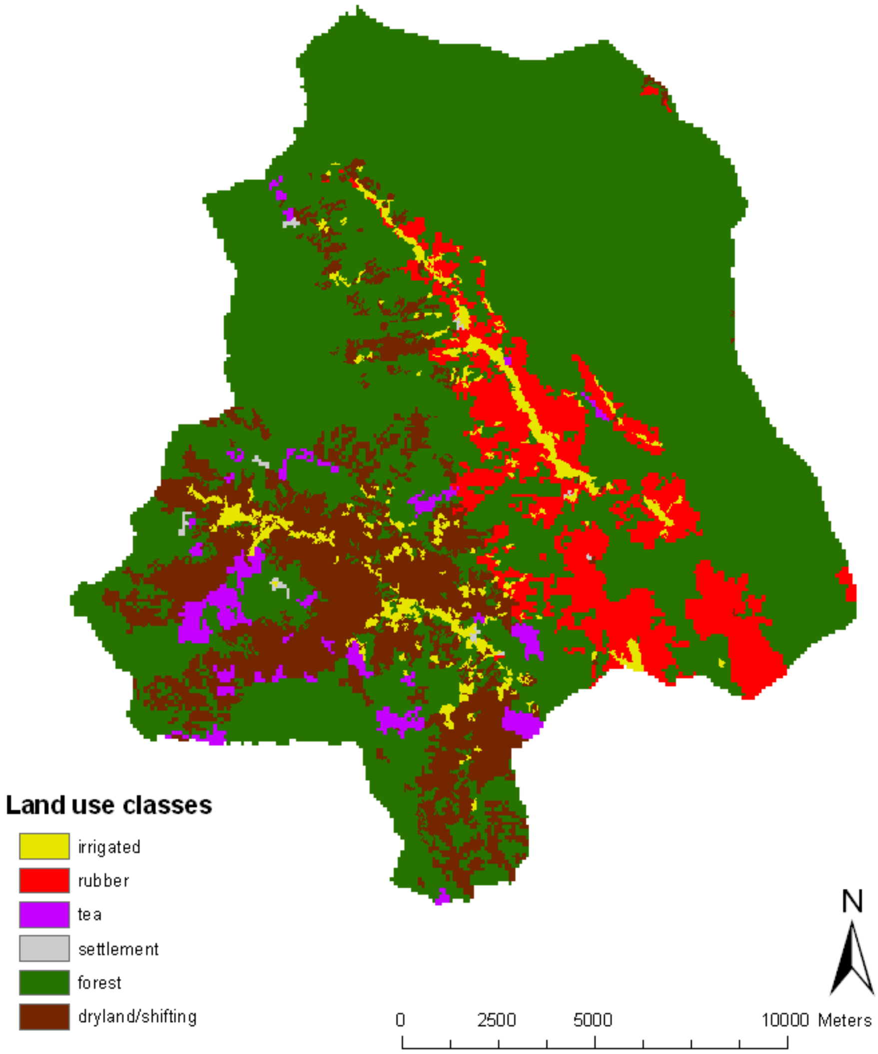

Figure 4.1 Land Use map of NRWNNR, derived from IKONOS satellite image using ERDAS Imagine by (Berkhoff and others 2009).

4.2.2 Flora

Floristic inventory data were analyzed considering factors like the occurrence of rare and endemic species (Beukema and Noordwijk 2004) and the value of a vegetation type for sustainable use by man, e.g. the collection of wild medicinal plants. Since the study area is managed according to MAB, we opted to include the anthropocentric criterion of usability, expressed through the number of medicinally usable plant species.

In NRWNNR, several types of tropical forest are the most abundant natural vegetation, namely lowland seasonal tropical rainforest, tropical montane rainforest and montane evergreen broadleaf forest (Zhu 2008).

The vascular plant diversity, except epiphytes, of major land use types at both high and low elevations within NRWNNR was recorded using plots of varying area (Table 4.1). With the help of botanists from the Xishuangbanna Tropical Botanical Garden of the Chinese Academy of Sciences (XTBG), plants were identified in the field and voucher specimens were collected for further identification at the Herbarium of XTBG.

A total of 18901 m^2 of land in NRWNNR were surveyed based on 610 plots, with different sizes for different land use types. Some 1,252 species from 635 genera and 158 families were identified.

Details of plot distribution and plant richness in each land use class are given in table 4.1. To analyze the conservational value of each land use class, detailed information on each species was collected from high level references (Table 4.1). In summary, our target species groups were: endemic (END), exotic (EXO) and invasive (INV) species, as well as IUCN Red List (RL) species and plants with a reported medicinal use (MED).

An important task in biodiversity assessment and conservation is to estimate the potential species number at a large spatial scale using a limited number of sampling units (Cao, Larsen and others 2004). Despite many techniques and indices that have been developed, we selected JackKnife1 due to its better performance with a small sampling area (McCune, Grace and others 2002). This procedure is giving us the possibility to eliminate the biases derived from varying sample sizes and to directly compare the species numbers of the land use classes.

Table 4.1 The proportion of target species groups found among the total plant inventory, shown for the different land use classes (LUC) and the number of plots, plot size and plant species (after JackKnife1) per LUC. Abbreviation used for indices: proportion of endemic (END), exotic (EXO), invasive (INV), IUCN Red List species (RL) and species with medicinal use (MED). A single species can fall into more than one category, endemic red list plant or invasive medicinal.

LUC	n plots	Plot size (m²)	n species	END	EXO	INV	RL	MED
Forest	45	400	796	0.15	0.11	0.09	0.11	0.26
Dryland	147	1	255	0.06	0.10	0.07	0.02	0.38
Irrigated	272	1	146	0.01	0.16	0.14	0.01	0.41
Rubber	88	25	518	0.09	0.06	0.04	0.04	0.37
Tea	58	1	124	0.02	0.12	0.11	0.02	0.44

Note: Endemic/Exotic/Invasive/Medicinal classification according to (Qian and Chen 1959-2004; Wu and Raven 1989; Xie, Li et al. 2001; Liu, Liang et al. 2005; Xu, Qiang et al. 2006; Weber, Sun et al. 2008; Wu et al. 2010); Red-list species according to (WCS 2005); Red-list species included CR (Critically Endangered), EN (Endangered), NT (Near Threatened), VU (Vulnerable)

4.2.3 Case study

Within the framework of the interdisciplinary LILAC project (lilac.uni-hohenheim.de), workgroups from social sciences, economy, landscape planning, hydrology and ecology have been working in the NRWNNR for the last three years identifying key drivers for and the resulting consequences of land use change in the research area. Based on these findings, possible future scenarios for the research area are being modeled and evaluated in regard to their impact on economy, ecology, hydrology, and social aspects. This integrated modeling and evaluation system is called NabanFrame (Berkhoff and Herrmann 2009).

4.3 Ecological indices (methods)

4.3.1 Land Use Classes (LUCs)

The “Forest” LUC covers all natural forest types ranging from tropical lowland rainforest to tropical evergreen broadleaf forest including bamboo forests. Dryland LUC covers rainfed maize and shifting cultivation, agricultural fallows and pastures used for cattle herding. Irrigated LUC implies terraced paddy rice. Tea and Rubber LUC include plantations with a strong human influence – clearly visible in satellite imagery - due to intensive management practices. This simplified land use classification was chosen in order to allow for a compromise between detailed plant data survey, modeling restrictions and reliability of remote sensing data. In addition, the research area was subdivided into topographic zones, namely uplands (above 1000m a.s.l.) and lowlands.

4.3.2 Flora indices

As a first step, the identified plant species were allocated to the target groups for each LUC (table 4.1). The share of each LUC in the study area was determined using ArcGIS Spatial Analyst. Ground truth and spatial analysis showed that these two topographic entities are clearly contrasting in their land use patterns. Both are dominated by forest vegetation, but the uplands are strongly influenced by rainfed agriculture and shifting cultivation, whereas in the lowlands paddy rice and rubber cultivation is the main agricultural activity at present (table 4.2, figure 4.2).

Table 4.2 Land use types within the research area, shown in total area as well as proportion of total, distributed below or above 1000m a.s.l. (lowlands, uplands).

LUC	Uplands		Lowlands		LU Naban	
	km²	proportion	km²	proportion	km²	proportion
Forest	126.9	0.70	62.3	0.69	189.2	0.70
Dryland	40.9	0.22	4.8	0.01	41.4	0.15
Irrigated	4.6	0.03	3.4	0.04	8.0	0.03
Rubber	2.7	0.02	23.2	0.26	25.9	0.10
Tea	5.9	0.03	0.1	0.00	6.0	0.02
Total	181.3	1	89.7	1	271	1

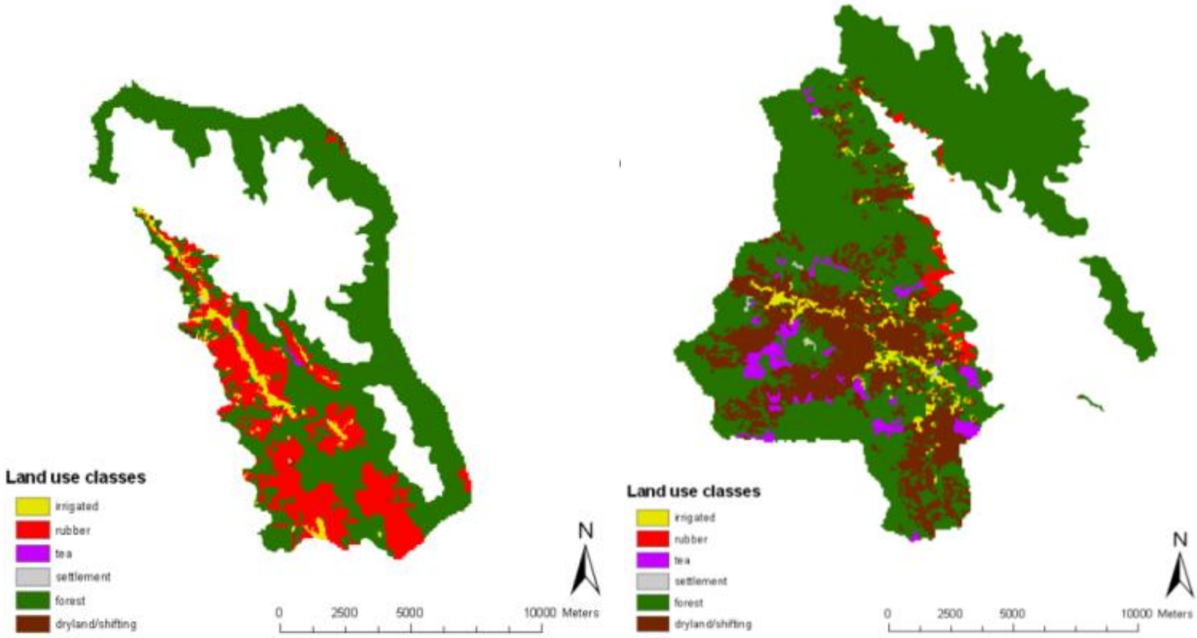

Figure 4.2 Land use maps for lowland (left map) and upland (right map) NRWNNR, divided along the 1000m a.s.l. line. Both are dominated by forests, lowland map is showing a strong influence of rubber plantations, whereas uplands have strong dryland/shifting agriculture.

In order to obtain area-wide information on species composition throughout the whole research area as well as within the two topographic regions, we decided to introduce area weighted mean indices for our target species groups. For this operation, the values for target groups within each land use class were multiplied by the proportional abundance of the land use class within the research area.

Example:

1) the proportion of forest land use types (0.7, see table 4.2) multiplied by the proportion of endemic species in forests END_forest (0.15, see table 4.1) results in an index value of 0.105, shown in table 4.3 as 10.5 ($x10^{-2}$) for better comparability.

2) the proportion of rubber land use type in lowland (0.26, see table 4.2) multiplied by the proportion of invasive species (0.04, see table 4.1) results in 0.01.

The resulting indices were summed up for all target species groups to provide an area wide assessment of species distribution and diversity (table 4.3).

Table 4.3 Area weighted mean (indicated by the suffix AM) species diversity for land use types in the study area (with their respective proportion) and summed up for evaluation of the research area. Abbreviation used for indices: area weighted mean proportion of endemic (END_AM), exotic (EXO_AM), invasive (INV_AM), IUCN Red List species (RL_AM) and species with medicinal use (MED_AM). Proportions and indices may not add up properly due to rounding for easier presentation. The values for the area weighted mean diversity indices are presented to the base of 10^{-2} for better presentability.

LUC	**Proportion** (LU Naban)	**END_AM** ($x10^{-2}$)	**EXO_AM** ($x10^{-2}$)	**INV_AM** ($x10^{-2}$)	**RL_AM** ($x10^{-2}$)	**MED_AM** ($x10^{-2}$)
Forest	0.70	10.5	0.8	0.6	8.0	18.2
Dryland	0.15	0.9	1.4	1.1	0.3	5.8
Irrigated	0.03	0.04	0.5	0.4	0.02	1.2
Rubber	0.10	0.8	0.6	0.4	0.4	3.6
Tea	0.02	0.04	0.3	0.2	0.04	1.0
LU Naban	**1**	**12.9**	**3.6**	**2.8**	**8.8**	**29.7**
Uplands	0.7	12.7	3.9	3.0	8.7	29.8
Lowlands	0.3	13.3	3.1	2.2	9.0	29.7

Note: the table can be read like this: the rubber land use class covers a proportion of 0.1 of the research area. It contributes 0.008 to the END_AM of the research area, as well as 0.006 to the EXO_AM. In total, the LU Naban covers the whole research area (proportion of 1), and the combined END_AM index is 0.129, and the combined MED_AM is 0.297. When comparing the upland to the lowland areas, one sees the difference in e.g. END_AM between the two topographic regions (0.127 to 0.133).

4.3.3 Landscape matrix analysis

The land use map was subjected to a sequence of analyses to quantitatively describe landscape structure (Opdam and others 2002, Jellema and others 2004). For this investigation, ArcGIS 9.2 by ESRI and FRAGSTATS 3.0 were used (www.esri.com, www.umass.edu). The GIS greatly accelerated the various transformations that were necessary to transfer the raster-based land use map into an ASCII file processible by FRAGSTATS.
Multiple preliminary tests with the software were run using parameters and extrapolations derived from field as well as from literature data (Ricketts 2001, Steiner and Köhler 2003).

The following indices, which have proven appropriate for the comparison of different landscape metrics (Lausch and Herzog 2002, Lang and Blaschke 2007) were calculated and used for this tool. For details on the mathematical procedures used for these indices, see the FRAGSTATS 3.0 manual (McGarigal and others 2002).

(1) Mean proximity of forest patches (PROX_MN): distances between forest patches and their respective area. The search radius was 100m around each patch of forest.

(2) Contagion (CONTAG) and interspersion: tendencies of a LUC to occur in direct proximity to patches of the same land use (clumpy distribution).

(3) Shannon's Diversity Index (SHDI): proportional abundance of LUC. SHDI is giving direct information about the evenness of area distribution among the different LUC.

(4) Area weighted mean patch fractal dimension (FRAC_AM): complexity of patch shapes considering the actual spatial coverage of the patches (e.g. large circular plots vs. small crescent-shaped gallery forests).

4.3.4 Case study

In order to assess the potential of NabanFrame we discuss one possible future land use scenario for our research area. This scenario has been derived from observation and analysis of the trends and development taking place in the Nabanhe watershed in the last 20 years. Our partner workgroup at the University Hannover has analyzed historical land use data and derived a linear extrapolation of the yearly change in land use distribution for the next 15 years. The basic assumption was that the factors governing land use change in the past will remain in place and continue their trends for the future (example: continuously rising demand for rubber on the global market leading to steadily increasing prices). Thus, the scenario is a "Business as usual" scenario. These assumptions are clearly simplified, but serve well enough to demonstrate the possibilities to conduct an ecological evaluation of landuse changes within the NabanFrame modeling framework (see table 4.4 for land use distribution). A map of the model predictions under the "Business as Usual" (BaU2025) scenario is given in figure 4.5.

Table 4.4 Proportion of land use classes for the situation today, and the scenario derived from linear extrapolation of historic land use change.

LUC	**LU Naban** (271.0 km²)		**BaU2025** (271.0 km²)	
	km²		km²	
Forest	189.2	0.70	169.9	0.63
Dryland	41.4	0.15	32.9	0.12
Irrigated	8.0	0.03	8.0	0.03
Rubber	25.9	0.10	48.1	0.18
Tea	6.0	0.02	11.1	0.04

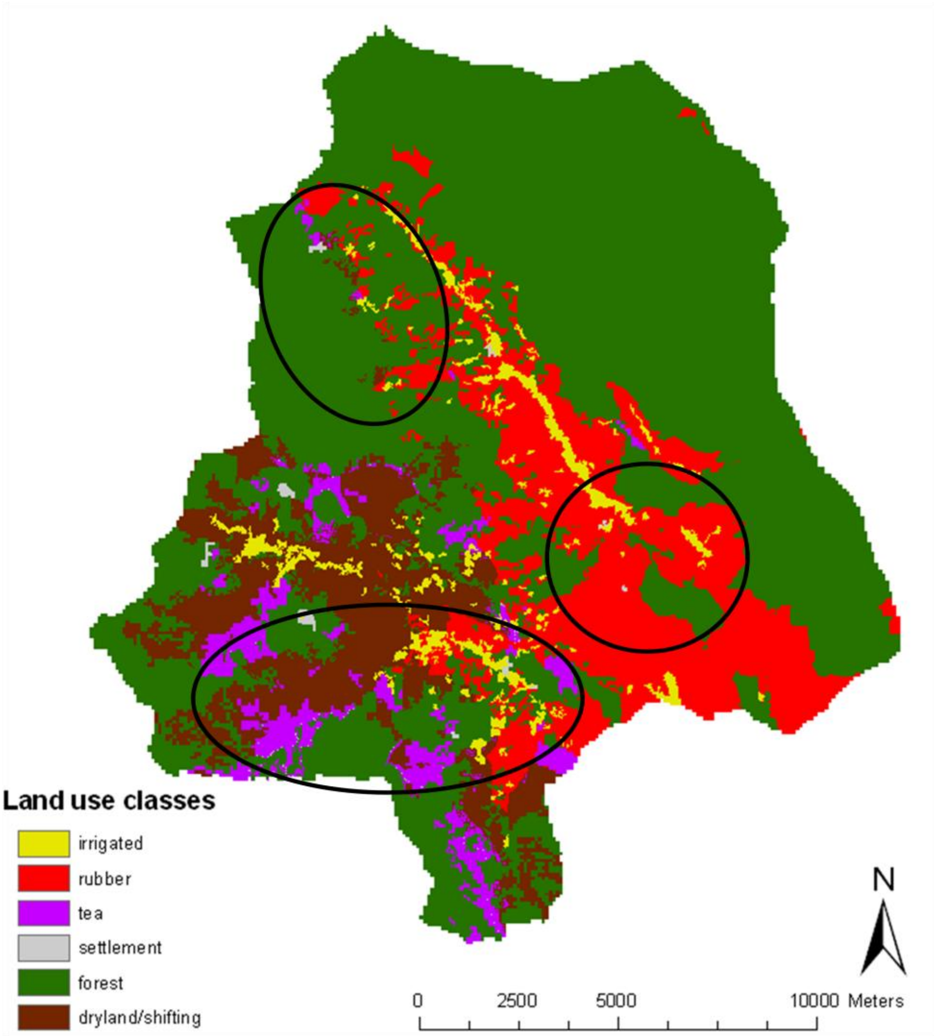

Figure 4.5 Land use map of BaU2025 exemplary scenario. Areas with the most prominent changes are indicated with circles. In lowland forest and dryland agriculture areas (centre right) as well as upland dryland areas (lower left) below 1400m a.s.l. where rubber cultivation is replacing the original land use. Dryland agriculture above 1400m a.s.l. is under strong pressure from tea plantations (lower left).

4.4 Results

4.4.1 Land use distribution

Although the research area is dominated by forest vegetation (70% in total), below 1000m a.s.l. we see a strong influence of rubber cultivation (total 10%, lowland 26%, upland 2%). The upland areas in contrast show a strong share of dryland/shifting cultivation (22%) and some tea plantations (3%), that are absent from the lowlands (table 4.2).

4.4.2 Plant species composition

Forests in the research area have the highest proportion of endemic (15%) and IUCN red list (11%) plants in their species inventory. The highest total species number can be found there (796 spp.). Rubber plantations rank second concerning species number (518 spp.), proportion of endemics (9%) and red list species (4%). Irrigated rice paddies and tea cultivation reached the highest values for exotic (16%, 12%) as well as invasive species (14%, 11%, respectively). The latter two land use classes were also those with the highest proportion of plants with medicinal use found in the research area (41% and 44%, respectively) (table 4.1).

4.4.3 Flora indices

Assessing the NRWNNR land use map as a whole resulted in high values for the area weighted proportion of endemic (0.129) and medicinal plants (0.297). Index values for exotic (0.036) and invasive plants (0.028) were low (table 4.3). When comparing the results for the different elevation levels, we see a strong tendency in the indices for endemic and invasive plants, pointing to lower levels of presence in the lowlands (-20.8%, -27.9%). The index for endemic plants is slightly higher (+5.3%) in the lowlands than in the uplands (figure 4.3).

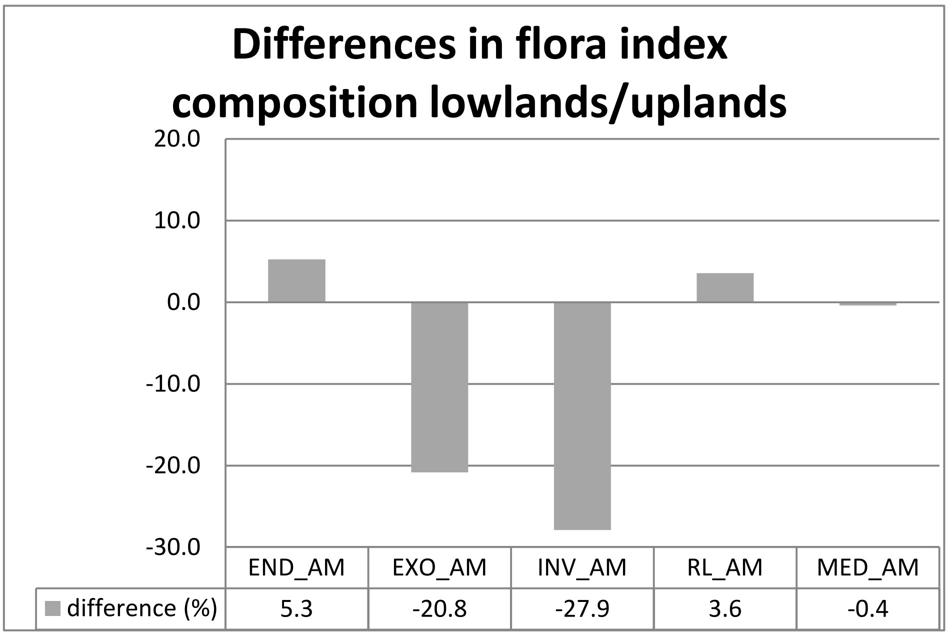

Figure 4.3 Difference between flora indices in the two topographic zones, uplands and lowlands along the 1000m a.s.l. borderline. Values are derived by dividing the lowland indices with the upland indices, results given as percentages. Positive values indicating higher indices in the lowlands, negative values higher indices in the uplands. Example: the exotic plants index EXO is 20.8% higher in the uplands compared to the lowlands. Abbreviation used for indices: area weighted mean proportion of endemic (END_AM), exotic (EXO_AM), invasive (INV_AM), IUCN Red List species (RL_AM) and species with medicinal use (MED_AM)

4.4.4 Landscape matrix

When comparing the results of the landscape matrix analysis the higher proximity of forest patches in the uplands compared to lowlands is striking (+53.6%). Contagion of land use patches is higher in the lowlands (+6.4%) where rubber plantations are an influential factor and the lower values for Shannon’s Diversity Index (-10%) point towards a less evenly distributed land use class coverage (figure 4.4).

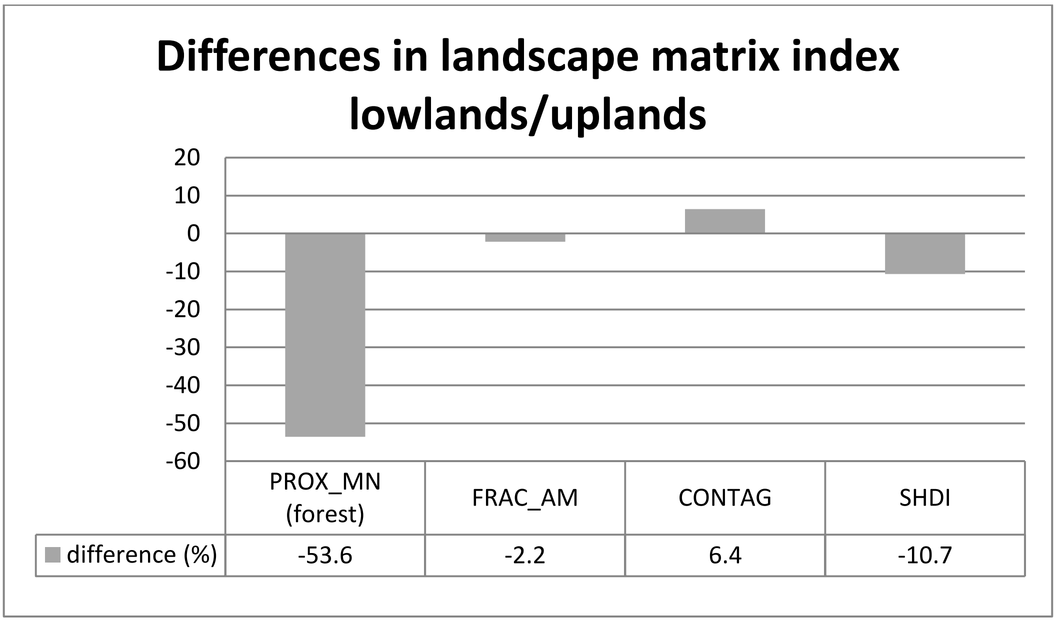

Figure 4.4 Difference between landscape matrix indices in the two topographic zones. Values are derived by dividing the lowland indices with the upland indices, results given as percentages. Positive values indicating higher indices in the lowlands, negative values higher indices in the uplands. Example: Proximity of forest patches is more than 50% higher in the uplands compared to the lowlands. Abbreviation used for indices: area weighted mean proximity of forest patches (PROX_MN), area weighted mean patch fractal dimension (FRAC_AM), Contagion (CONTAG) and Shannon's Diversity Index (SHDI).

4.4.5 Case study

When applying our proposed ecological toolset to the scenario's land use map, we see changes in the composition of flora indices as well as in the landscape matrix indices. Based on the results of these analyses, we would expect the proportion of endemic and IUCN red list species to decrease due to the reduction of forest cover (from 70% to 63%) mainly in the communal lowland areas, but also due to the increase in tea cultivation (from 6% to 11%) in the highlands, which is a rather species poor environment. The increasing distance between forest patches could be seen as a potential risk to species distribution and pollination. The increase of the SHDI (+14.9%) points to a more even distribution of land use types, indicating a decrease in forest dominance over the research area. The reduction in the contagion index (-6.1%) is explained by a clearing out or smoothing of the landscape. See results in figures 4.6 and 4.7.

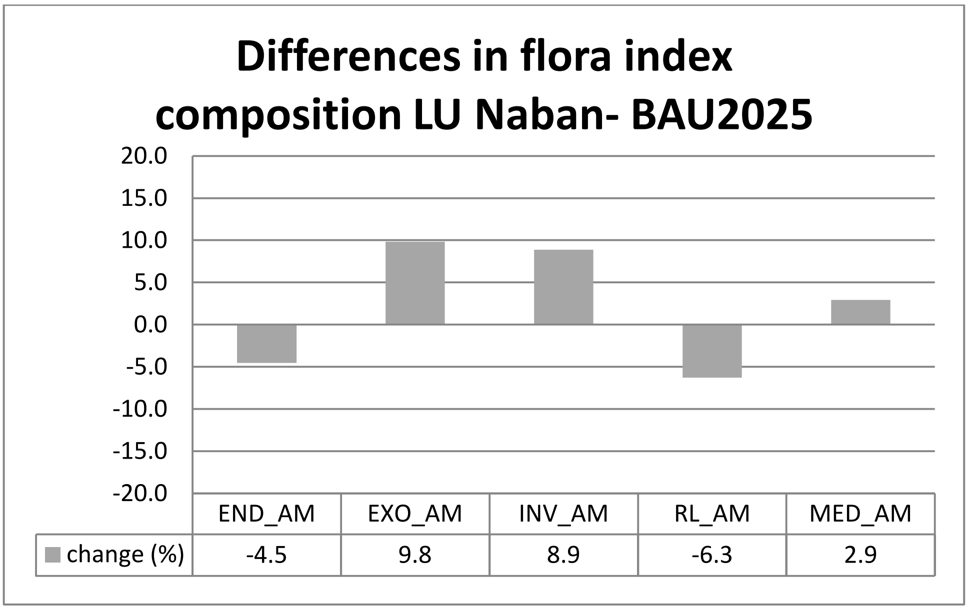

Figure 4.6 Differences in flora indices when comparing the recent land use map with the business as usual scenario for 2025. Values were derived by dividing the LU Naban values by the BaU2025 values, results are given as percentages. Abbreviation used for indices: area weighted mean proportion of endemic (END_AM), exotic (EXO_AM), invasive (INV_AM), IUCN Red List species (RL_AM) and species with medicinal use (MED_AM).

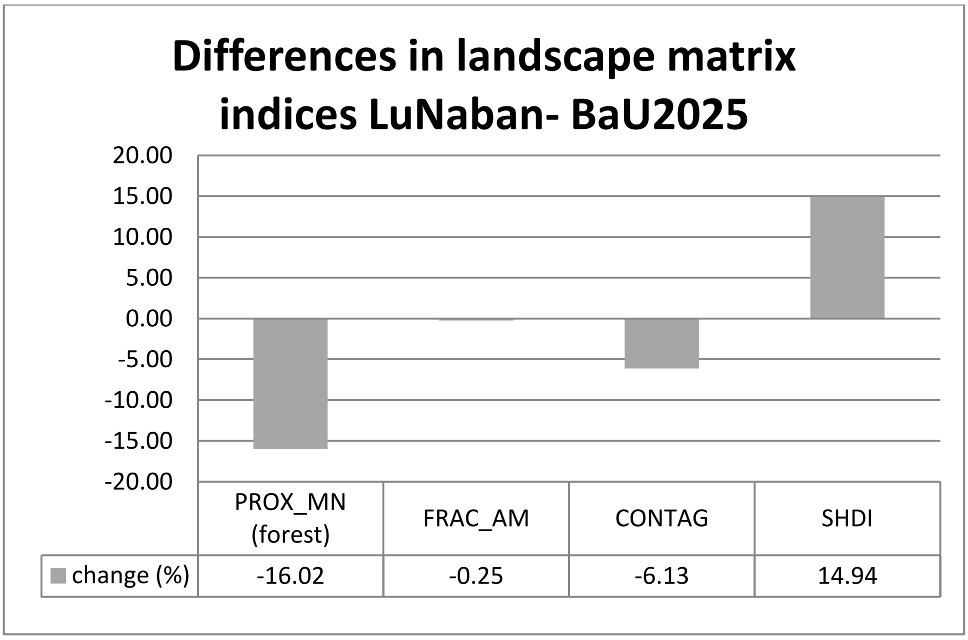

Figure 4.7 Differences in landscape matrix indices when comparing the recent land use map with the business as usual scenario for 2025. Abbreviation used for indices: area weighted mean proximity of forest patches (PROX_MN), area weighted mean patch fractal dimension (FRAC_AM), Contagion (CONTAG) and Shannon's Diversity Index (SHDI).

We also analyzed the BaU2025 scenario with regard to changes in the topographic zones (as described in methods) of the research area. In the BaU2025 scenario, the expansion of rubber plantations in the lowlands at the cost of forest and farmland leads to the point where dryland farming is heavily reduced in lowland areas. A similar pattern can be seen in the uplands, with the exception that rubber farming is reaching a physiological production limit at an elevation level of 1400m a.s.l.. Above, forest and dryland land use classes are being replaced by tea cultivation, which yields relatively high profits for the farmers, but is generally resulting in a very uniform and species-poor environment unless more diversity-promoting tea production systems are adapted.

4.5 Discussion

4.5.1 Land use class distribution

In the research area, rubber farming is driving a block of uniform plantations into a diverse mosaic of land use systems, resulting in lower forest connectivity in the lowlands, where the remaining forest patches are at a greater distance from each other. At the same time contagion is higher, as this anthropogenic land use tends to appear close to other patches of already existing rubber cultivation. Rubber cultivation is scarce in the upland area, as the economic threshold of rubber farming is at around 1000 m a.s.l. at present, but establishment of cold tolerant cultivars is currently taking place also above this elevation line.

Both topographic zones are dominated by forest, but the uplands are mainly used for dryland or shifting cultivation with some small areas of tea cultivation in between (table 4.2). Land use classes are more evenly distributed in the uplands, as indicated by the higher values for the SHDI (Shannon's Diversity Index). The high proximity of forest patches can be explained by the fact that most forest areas in the uplands form a belt shaped macro structure along the borders of our research area, thus being relatively close to the next patch along this belt (figure 4.4).

4.5.2 Floral indices

The results of this research back the notion that tropical rainforests should be the centre of concern for biodiversity conservation in the tropics. But also human-made ecosystems can deliver a relatively high contribution to species diversity. But, as can be seen with the indices developed here, this contribution has to be analyzed further. Many of the species growing in fields or paddies are exotic species (a lot of them ubiquitous) that increase species richness of the research area, but do not add to the conservation value of the reserve.

Dryland agriculture hosts a higher proportion of invasive and exotic species than rubber plantations do (table 4.1), mind the higher indices for the upland areas. On the other hand, rubber plantations are the land use class with the second highest species diversity and number of endemic species. Optimized and ecologically sound rubber plantations could be, if managed sustainably without rampant herbicide use, a good way to join the economic interest of farmers with the need for conservation, especially in such a complex frame as a MAB reserve.

4.5.3 Methodology

This proposed toolset is designed to be used by conservation, planning and administration practitioners and scientists alike. With this broad range of target audiences, we decided to keep it simple. Most of the information needed for an adoption of this methodology should be available, be it species composition data for a nature park, or land use distribution for rural development. We see a particular strength of this toolset in scenario evaluation, where possible future land use scenarios have to be assessed according to their impact on biodiversity. See the case study below as an example.

Other studies have proposed various ways to cope with the tasks mentioned above. Machado (2004) has stated that due to the demand from conservation management, rapid landscape evaluation methods need to be developed that rely on time- and effort-efficient data requirements. He proposed to split land use classes into 10 categories, from artificial, nearly lifeless systems to natural virgin systems. These classes are ranked according to the descriptive conditions related to the naturalness of the vegetation and the impact of human activities. This method gives an overview over the extent of human impact in a given region, and allows for a relatively fast assessment of its' state, but its' rough classification of categories does not allow for a detailed analysis of, for example, plant species composition. Pristine ecosystems are the highest category, whereas highly diverse, species rich and extensively managed forage or cropping systems that could harbor a multitude of threatened or endemic plants end up in rather low categories. Our proposed tool offers a clearer focus on species diversity conservation, while integrating the impact on landscape composition into the analysis. Zebisch and others (2004) tested the feasibility of combining measures for the impact of human disturbance with biodiversity assessments based on the analysis of landscape structure and derived indices. These were applied to different land use scenarios in order to assess the scenarios' impact on biodiversity. This method uses indices for LUC composition and richness as well as indices for landscape structure derived from the proximity of favorable LUCs. While the assessment of possible landscape matrix effects is very helpful for conservation and biodiversity management planning and helps to identify key factors of possible future developments, their use as proxies for biodiversity is lacking from an ecological point of view. Trisurat and others (2010) tested the applicability of the GLOBIO3 biodiversity assessment model (Alkemade and others 2009) to land use change assessment in a tropical environment. This model uses relative mean species abundance (MSA: species composition compared to pristine ecosystems in the region) as a proxy for biodiversity. Literature review was supplying the values for MSA, and buffers along the road system were used to reduce MSA values to take into account human influence. This procedure was used to evaluate land use scenarios for Northern Thailand in order to identify mayor threats to biodiversity and possible conservation hot spots. The use of pristine ecosystems as a benchmark to evaluate biodiversity has proven difficult in our research. Even in remote areas, the impact of human interference was visible by selective logging, gathering of forest products or hunting. Areas that could serve as a proper benchmark are often inaccessible, either through topographic or administrative reasons. The combination of an assessment on a landscape scale with quantitative data derived from detailed field work as proposed in this article will allow a more detailed analysis of scenarios derived from multidisciplinary research projects, but also from administrative planning procedures. The method presented here can be easily adapted for using already existing datasets from nature reserves, and can be applied by administrative personal even without years of training in the field of landscape ecology, botany or entomology.

4.5.4 Ecological relevance

We have decided not to include Ecosystem Services and Ecosystem Functions (ESS/ESF, Costanza and others 2000) in general into this biodiversity evaluation tool, as we clearly wanted to focus on the analysis of biological and structural diversity in a given landscape. In order to fully assess the potential ESSs and ESFs, a far broader range of experiments has to be conducted, and a wide scope of economic and social data would have to be gathered additionally. Although it is desirable to aspire such a holistic dataset, the situation in the field and the availability of datasets or time concern often impairs such an enterprise (Machado 2004). By focusing on the ecological data that can either be acquired during a project's research phase or that even could be available from the reserve administration authorities as part of their inventory data we aim to provide a sturdy and manageable tool for the assessment of biodiversity.

4.6 Applicability

The methods presented here are meant to provide scientists, administration and policy makers with an adaptable tool for the evaluation of landscapes, municipalities or nature reserves. Our current work is focused on the Greater Mekong Subregion, but the underlying concept of GIS-based landscape analysis using benchmark comparison and ecological indices can easily be transferred to other regions in the tropics and subtropics that face similar problems concerning deforestation and massive land use change. Situations of special interest could be the establishment of plantations for the production of renewable primary products such as oil palm in South East Asia, the large scale production of animal feed in the Amazon basin and Cerrado of Brazil, or the changes in landscape composition caused by smallholder farmers on the margins of the rainforests of Africa and South America.

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5. Designing a "Go Green" scenario for sustainable land management in Southwest China

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Outline and overview

The work presented in chapter five represents one of the major steps in the modeling processes of the LILAC project. With the assemblage of data that has been collected during nearly three years of field work, the final stages of the scenario design process were approached. Various preliminary propositions had been discussed, and a guideline for the integration of the disciplinary research work into the storylines had to be developed. Together with Dr. Karin Berkhoff, who was responsible for integrating the datasets into the land use change model, the work steps and methodology presented in the following chapter have been designed. It covers the design and development process for a land use scenario based on the integration of multidisciplinary assessments and iterative scenario refinement with repeated stakeholder inclusion. This chapter can serve as guideline for future projects that try to implement scenario design procedures based on the combination of social sciences, economics, ecology and landscape planning.
The findings presented in chapter two and especially in chapter four enabled the ecology workgroup to supply the economy and land use change models with clear information on the ecological "value", represented in species diversity and diversity index composition, for the different land use classes, a process that was necessary for the design and implementation of the storylines used in LILAC. Chapter four's model was used to evaluate the effects of the different storylines on the resulting scenarios' species diversity and landscape composition. An exemplary abridgement can be found in chapter seven.

Designing a "Go Green" scenario for sustainable land management in Southwest China

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Abstract

Land use change and the corresponding effects on eco-systems and their services has gained much interest in the recent past, particularly in areas with a significant reservoir of biodiversity, the so called biodiversity hot spots. In order to assess the impact of possible future land use decisions in a watershed in Yunnan, Southwest China, we applied a method of combining ecological, hydrologic and socio-economic indicators to highlight key aspects concerning the current status of our research area. Data on species diversity, landscape matrix and erosion risk as well as agricultural and socio-economic activities were gathered and analyzed. We were able to locate the areas were conservation measures, erosion control and improved agricultural practices would have the strongest impacts. This information was used to develop a storyline for a “Go Green” scenario. Expert groups and an international panel discussion were used to critically review, enhance and expand this storyline in the area of conflict between nature conservation, rural livelihood and economic development.

Based on the set of planning prerequisites, a village-household linear programming model was developed and solved with the General Algebraic Modeling System (GAMS) to identify factors driving landscape and land use changes for three different farming systems in the Naban River Watershed National Nature Reserve, mainly to contribute to the CLUE_Naban model by providing representative farm types and to analyze the decision making of land use (until 2025). In addition, this model is designed to provide policy makers with potential strategic intervention options for land use planning through the utilization of shadow prices.

This process enabled us to reconcile the demands for nature conservation and economic wellbeing on a basis of an iterative and participatory working process that incorporates ecological and economic datasets, but also takes the sustainability of rural livelihood into account.

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Keywords

scenario design, land use change, rubber, biodiversity, modeling, Greater Mekong Subregion

5.1 Introduction

The Xishuangbanna Prefecture in Yunnan Province (PR China) is facing increasing conflicts with regard to rural development and nature conservation because of the rapid commercialization of farming. The situation is similar to a multitude of other rural areas in the Greater Mekong Subregion (GMS). The rapid development of large-scale farming and the improvement of infrastructure throughout the region are posing serious threats to the conservation of endemic species of flora and fauna, but are also offering possibilities for enhancing the livelihood of rural populations on a scale never seen before (Lawrence 1996, UNESCO 2007, Steffan-Dewenter et al. 2007). Unsurprisingly we encounter a trade-off between economic development and biodiversity conservation competing for the same resources. So far, economic goals have dominated: i.e. from 1976 to 2003, 140’000 ha of tropical rainforest were replaced by rubber (*Hevea brasiliensis*)(Li et al. 2007). Forest clearing has continued since then. In the last decades, the cultivation of rubber has increasingly gained importance in the Greater Mekong Subregion due to economic reasons such as China’s wish for autarky for rubber and as a pathway to promote the commercialization of farming systems, displacing traditional land use systems like forest gardens or shifting cultivation. The expansion of rubber has caused a reduction and fragmentation of natural and near-natural forests, with all the consequences like a decrease in structural and bio-diversity as well as the loss of valuable ecosystem services (Wu et al. 2001, Zhu et al. 2006). The establishment of intensified agriculture, especially plantations and farming by monocropping (after the clearing of forests) on sloping terrain often leads to an increased risk of erosion, nutrient run-off and sedimentation in water courses. Thus, the deforestation taking place all over the region is not just a problem of nature conservation but also one of the rural economies, if one aims at enduring support from nature. Besides, more and more people begin to feel the negative impacts of land use change along the Mekong.

> The research area, to which our models and scenario building methodology is applied, is the Naban River Watershed National Nature Reserve (NRWNNR, 22°08’N 100°41’E) in the province of Yunnan, PR China. Yunnan is part of the Indo-Burmese "hot-spot of biodiversity” (Myers et al. 2000). The nature reserve covers 271 km² and its elevation ranges from 500 m to 2300 m above sea level. It is covering the watershed of the Naban River, which is a tributary of the Mekong River (Lancang Jiang). It features an especially high diversity of natural vegetation types, as well as hosts a big variety of land use systems due to the topographically and ethnically diverse history of the region (Zhu 2008).

Change in land use, in this case the fast growing number of rubber plantations, also have a distinct link to water fluxes in catchments’ hydrology. Rubber is not an indigenous plant in the research area and hence not adapted to the local water yields. Given this background the modelling group of our LILAC project (Living Landscapes China) decided to extend the NabanFrame modelling framework with a hydrological model AKWA-M® (Wahren et al. 2010a,b) on water distribution for the GMS. It delivers information on water fluxes in the study area. Simulation results are included in the synthesized approach and help to assess the land use impact on both site water fluxes and catchments as well as recognizing water balances.

It is plausible to anticipate that the mentioned changes in land use may have modified the water balance and cycling (soil water supply, evapotranspiration, groundwater recharge). As a consequence plant production and run-off, and thus, also soil erosion in the rainy season may have been subject to distinct changes. However, the available land for the land use changes in the NRWNNR is limited due to the protection status in the core zone and the non-remunerative regions in the higher elevations. Therefore the consequences for catchment water balance for the whole Naban river basin are small. Locally the impacts can be pronounced, especially considering the soils which have a high erodibility (Felix-Henningsen et al. 1989, Barton et al. 2004) in this region with a high morphological energy.

However, one has to notice that rubber cultivation is well accepted among local land users, as its introduction has had remarkable impacts, such as the improvement of income, infrastructural advances and enhanced access to welfare and healthcare facilities (Tang et al. 2009, Xu et al. 2005).

In order to highlight possible alternative pathways for the future development of the region, there is a need to simulate scenarios e.g. our “Go Green” scenario which can be used to test different options in creating favorable socio-ecological situations. Another possibility would be to compel the village farm households to limit the rubber to certain areas and to not allow a spread all over the natural reserve of Nabanhe. This can be reached through incentives based compensation for agricultural land going out of rubber; we can speak of a retirement policy. However, voluntary land retirement policies may require compensation payments to landholders to cover the costs of converting the land to non-agricultural use or ecologically conducive crops, this means to recognize the opportunity cost of land. Knowing the value of a land parcel over a year (the so-called shadow price of land) indicates the likely value of necessary compensation payments. Payments might be required for a policy to be successful. Consequently, we obtain “shadow prices”, which are linked to costs and benefits in rubber growth and they reveal payments as costs for governments to make the area more sustainable. For explanation: in constrained optimization in economics, the shadow price is the change in the objective value of the optimal solution of an optimization problem, if a constraint is changed (i.e. a government wants less rubber). It is obtained by relaxing the constraint by one unit – this is then the marginal utility of relaxing the constraint, or equivalently the marginal cost of strengthening the constraint. As alternative to rubber in monoculture, we suggest applying a proposed agroforestry system focussing on the sustainable cultivation of Traditional Chinese Medicine (TCM) plants. This shall take place within the boundaries of community forests and it aims to demonstrate the potential of shadow prices when assessing agricultural land use alternatives.

Traditional Chinese Medicine plays an important role in the health care system of China. Including allopathic medicine, TCM provides 30-50% of health care delivered, at least in rural areas such as the NRWNNR (WHO, 2001). In the last years demand and consequently the market for traditional medicinal products has seen a large increase. The Traditional Chinese Medicine is one of the oldest and deeply rooted medical systems of the world. Since 1979 it has seen a demand increase by 9% per year (Handa et al. 2006) within China. According to the Hong Kong Trade Development Council (TDC), the global Chinese medicine market is worth US$20 billion a year (ITC, 2003). A majority of medicinal plants used in TCM are collected from wild resources which due to the increase in demand, has resulted in overexploitation and depletion of wild resources of TCM plants (Hamilton, 2004; Leman, 2006). This is also the situation present in the area investigated. Any efforts for cultivation and conservation of medicinal and aromatic plants would help to provide employment, additional income for farmers and preserve the natural resources.

In order to assess the impacts of management and land use planning decisions in such a diverse and potentially also volatile environment, tools and methods have to be developed that take into account the particular needs of rural areas facing drastic changes in their economic and natural environment. Future land use scenarios are used to highlight possible impacts of intervention and decision making processes on land use, structural development and economic stability.

Our research is based on the assumption that it is possible to reduce the threats of biodiversity loss and erosion risk while improving livelihoods of local inhabitants and enhancing their socio-economic and cultural conditions. As Xishuangbanna is a member of the UNESCO Man and the Biosphere (MAB) network since 1993, the idea is to aim for more sustainability, touching on the environmental, economic and social aspects simultaneously, as postulated by the MAB Programme of UNESCO. To test this hypothesis, we designed a “Go Green” Scenario. This scenario was based on a storyline that describes a more sustainable management of resources in the study area. We followed an approach of integrating disciplinary models in a synthesized approach within one modeling framework. To do so, in this scenario, we wanted to find a compromise between the economic value of land and the value of the land for the environment’s sake (e.g. biodiversity, hydrology).

An interdisciplinary modelling approach was considered necessary to balance the different demands and options for future land use distribution.

5.2 Material and Methods

When developing plausible scenarios for possible future land use in any given area, scientists and administrative planners can opt for a multitude of options ranging from (1) artistic interpretation (2) popular census, (3) strict continuation to (4) extrapolation of past trends in land use change. We opted for a combination of scientific field work based on data of the current situation derived from economic, ecological and social sciences, with expert opinions based on local expertise, obtained from local stakeholders, practitioners and scientists from or working in the study area. During multiple interdisciplinary expert meetings and with the input of local experts received from individual contacts we have been able to develop storylines for more sustainable and biodiversity friendly scenarios of land use projecting our findings to the year 2025. The main goal was to combine the MAB principles of (1) conservation and (2) sustainable livelihood within the NRWNNR with (3) aspirations of the communities and (4) government aims, without neither proposing economically unrealistic or socially undesired developments nor confining the scenarios to disciplinary navel-gazing. Four main assumptions had to be parameterized in order to do so.

(1) A stronger protection of the most ecologically valuable land use types in order to secure the future of conservation efforts within the area.
(2) A reforestation of farmland on sloping terrain to reduce the impact of soil erosion.
(3) An introduction of more sustainable alternatives to rubber monoculture based on an increasing demand for Traditional Chinese Medicine plants being met by community based agroforestry systems.
(4) An assessment of the impact of rubber cultivation on the ecological, economic and social situation in the NRWNNR.

Additionally we had to make some assumptions on external factors driving the scenario design process that we could not assess otherwise, such as a stable demand for raw rubber from the world market, slightly improved and adapted *Hevea* varieties as well as a stable and increased demand for TCM products.

5.2.1 Balancing the management objectives of income generation and biodiversity conservation with the help of shadow prices

In order to assess the current situation in the research area several extensive surveys on the socio-economic situation of the village farmers have been conducted over a period of two years. Data on agricultural activities and household income, but also on the economy of rural labour, education and social well-being had been recorded. Complementary, data sets on plant and insect diversity have been gathered all throughout the NRWNNR, as well as remote sensing based land use and elevation maps. Information and data banks were jointly created to provide a base for consistent analysis.

5.2.1.1 Shadow prices in GAMS model

A village-household linear programming model was developed and solved with the General Algebraic Modelling System (GAMS) software, mainly to contribute to the CLUE-Naban model by (1) providing representative farm types, (2) to analyze the decision making of land use, and (3) to provide policy makers with potential strategic intervention options for land use. Three different farming systems in the NRWNNR were investigated. Eight villages located at three different altitudes (high-land >1400m, middle-land 800-1400m and low-land <800m) in the NRWNNR were selected and intensively surveyed for the study. A total sample of 103 households was obtained and interviews conducted for the required information, which pertains to the agricultural year of 2007 and 2008. In addition, we gathered data on TCM collection and use. This data covered 51 village households at five villages classified to belong to Region-1 according to CLUE-Naban classification (Berkhoff et al, to be published 2011).

5.2.1.2 The model objective function

A fundamental nature of linear programming models is the fact that it works with constrained optimization of an objective function. The objective function specifies the preferences of a decision maker, in our case the farm household. We assumed households in the NRWNNR achieve the production and consumption goals, simultaneously. This is assumed because many households in the study area are subsistence households; note though subsistence farmers may also sell surpluses of cash crops on the market, their objective is primarily to get food from farming and exchange rather than income. Accordingly, we assumed that food consumption has indeed the highest priority for the farm households in the NRWNNR villages, and that sufficient food for the family is a requirement that needs to be fulfilled (in programming). Then we looked at a time span of several years. Hence, the objective function values were discounted by a discount rate of 5.3% according to Bank of China, and we worked for a time horizon of nineteen years in the future. The model is specified at the village level, because in the NRWNNR many natural resources such as grazing land and fuel wood are managed at the village level.

5.2.1.3 Land shadow price: a policy option for conservation

Under conditions such as can be found in the research area it is obvious that conservation matters. A desired impact of farming should be to maintain the traditional landscape for multiple environmental benefits including reduced soil erosion, improved water quality and protected wildlife habitats. Therefore, there was a need to simulate a scenario which can test different options to create a favorable socio-ecological situation: one of which is the TCM and forestry conservation approach.

The impact of various policy scenarios on factor use and inputs used in production can be evaluated through the shadow price analysis (Hazell and Norton, 1986). Hence, according to Raguragavan et al. (2009), knowing the value of a land parcel over a year (the so-called shadow price of land), shadow prices indicate the likely value of the compensation payment required for a policy to be successfully accepted. We obtained in our research “shadow prices”, which are linked to costs and payment costs. To calculate the shadow price on a unit basis, the following formula was used:

Shadow price = Δ (objective function)/ Δ (constraint) at the optimum

Compensations could be directly paid in cash or in tax exemption benefit for individuals through development compensatory program. Our research focused on alternative options in order to show how a village farm household can convert his land into more sustainable activities rather than rubber. For that purpose we simulated the model to cultivate leased land with TCM plants.

5.2.2.1 Plant species diversity

A total of 610 plots were surveyed within the NRWNNR, with varying plot sizes according to the respective vegetation types (1252 species from 635 genera and 158 families were identified, Liu et al., in preparation). To analyse the conservational value of each land use class (LUC) (Berkhoff et al. 2009), detailed information on each species was collected from high level references (see footnote table 5.1). An important task in biodiversity assessment and conservation is to estimate the potential species number at a large spatial scale using a limited number of sampling units (Cao et al. 2004). The JackKnife1 method was used to remove sampling biases due to its better performance with a small sampling area (McCune et al. 2002).

The identified plant species were allocated to the target groups for each LUC (table 5.1). The share of each LUC in the study area was determined using ArcGIS Spatial Analyst.

In order to obtain area-wide information on species composition throughout the whole research area we decided to introduce area weighted mean indices for target species groups (similar approaches can be found in Trisurat et al. 2010 and Alkemade et al. 2009). For this operation, the values for target groups within each land use class were multiplied by the proportional abundance of the land use class within the research area. This research used the proportion of endemic (END), exotic (EXO) and invasive (INV) species as well as the mean number of IUCN Red List (RL) species and plants with a reported medicinal use (MED) found in the plots for these calculations (for more information see Cotter et al., in review, chapter four).

e.g.: the proportion of forest land use types (0.7, see table 5.2) multiplied by the proportion of endemic species in forests END_forest (0.15, table 5.1) results in an index value of 0.105.

The resulting indices were summed up for all target species groups to provide for an area wide assessment of species distribution and diversity (table 5.2). This method allows a comparison of sub-regions within the research area as well as the evaluation of different land use scenarios based on future land use decisions.

Table 5.1 Target species groups found among the total plant inventory, shown for the different land use classes (LUC) and the number of plots, plot size and plant species (after JackKnife1) per LUC. Abbreviation used for indices: proportion of endemic (END), exotic (EXO), invasive (INV) species; mean diversity of IUCN Red List species (RL) and species with medicinal use (MED). A single species can fall into more than one category, endemic red list plant or invasive medicinal. Total species number was 1252.

LUC	**n** plots	**Prop.** of total	**size** (m^2)	**(n)** plant spp.	**END** prop.	**EXO** prop.	**INV** prop.	**RL** spp.	**MED** spp.
Forest	45	0.70	400	796	0.15	0.11	0.09	91	208
Dryland	147	0.15	1	255	0.06	0.10	0.07	6	92
Irrigated	272	0.03	1	146	0.01	0.16	0.14	1	60
Rubber	88	0.10	25	518	0.09	0.06	0.04	20	193
Tea	58	0.2	1	124	0.02	0.12	0.11	2	55

Note: Endemic/Exotic/Invasive/Medicinal classification according to (Qian and Chen 1959-2004; Wu and Raven 1989; Xie, Li et al. 2001; Liu, Liang et al. 2005; Xu, Qiang et al. 2006; Weber, Sun et al. 2008; Wu et al. 2010); Red-list species according to (WCS 2005); Red-list species included CR (Critically Endangered), EN (Endangered), NT (Near Threatened), VU (Vulnerable)

5.2.2.2 Insect diversity

An adapted approach was used to assess insect diversity datasets. Sampling transects equipped with Malaise, canopy and pit traps were set up in five different locations throughout the research area, and insect species composition was analyzed over a period of three years (2007-2010). Species distribution for three main target groups ground beetles (Carabidae) , hover flies (Syrphidae) and wild bees (Apidae) was analyzed in relation to the three main habitat types found in the research area; open land, forest and rubber plantations (Meng et al., in preparation).

Three area weighted mean indices for the presence and suitability of occurring habitats were calculated by multiplying the mean proportion of target insect group individuals per trap with the proportion of each habitat type in the research area.

The resulting indices were summed up for all habitat types, resulting in a research area wide coverage of habitat suitability for each of the three target insect groups (table 5.2).

Table 5.2 Area weighted mean (indicated by the suffix AM) species diversity for land use types in the study area (with their respective proportion) and summed up for evaluation of the research area 2006/2007. Abbreviation used for indices: area weighted mean proportion of endemic (END_AM), exotic (EXO_AM), invasive (INV_AM) species and area weighted mean diversity of IUCN Red List species (RL_AM) and species with medicinal use (MED_AM), area weighted mean Wild Bee index (WBI_AM), area weighted mean Hover Fly index (HFI_AM) and area –weighted mean Ground Beetle index (GBI_AM). Proportions and indices may not add up properly due to rounding for easier presentation. The values for the area weighted mean diversity indices are presented to the base of 10^{-2} for better presentability.

<table>
<tr><th></th><th></th><th colspan="5">Flora</th><th colspan="3">Fauna</th></tr>
<tr><th>LUC</th><th>Prop</th><th>END_AM ($x10^{-2}$)</th><th>EXO_AM ($x10^{-2}$)</th><th>INV_AM ($x10^{-2}$)</th><th>RL_AM</th><th>MED_AM</th><th>WBI_AM ($x10^{-2}$)</th><th>GBI_AM ($x10^{-2}$)</th><th>HFI_AM ($x10^{-2}$)</th></tr>
<tr><td>Forest</td><td>0.70</td><td>10.5</td><td>0.8</td><td>0.6</td><td>63.5</td><td>145.2</td><td>5.8</td><td>10.1</td><td>1.27</td></tr>
<tr><td>Dryland</td><td>0.15</td><td>0.9</td><td>1.4</td><td>1.1</td><td>0.9</td><td>14.1</td><td rowspan="3">0.5</td><td rowspan="3">4.3</td><td rowspan="3">1.3</td></tr>
<tr><td>Irrigated</td><td>0.03</td><td>0.04</td><td>0.5</td><td>0.4</td><td>0.03</td><td>1.8</td></tr>
<tr><td>Tea</td><td>0.02</td><td>0.04</td><td>0.3</td><td>0.2</td><td>0.04</td><td>1.2</td></tr>
<tr><td>Rubber</td><td>0.10</td><td>0.8</td><td>0.6</td><td>0.4</td><td>1.9</td><td>18.5</td><td>0.3</td><td>0.5</td><td>0.3</td></tr>
<tr><td>Total:</td><td>1.00</td><td>12.9</td><td>3.6</td><td>2.8</td><td>66.4</td><td>180.7</td><td>6.6</td><td>15.7</td><td>2.9</td></tr>
<tr><td>Uplands</td><td>0.70</td><td>12.7</td><td>3.9</td><td>3.0</td><td>65.4</td><td>172</td><td>6.6</td><td>16.6</td><td>3.0</td></tr>
<tr><td>Lowland</td><td>0.30</td><td>13.3</td><td>3.1</td><td>2.2</td><td>68.5</td><td>197</td><td>6.8</td><td>14.0</td><td>2.6</td></tr>
</table>

Note: the table can be read like this: the rubber land use class covers a proportion of 0.1 of the research area. It contributes 0.008 to the END_AM of the research area, as well as 0.006 to the EXO_AM. In total, the LU Naban covers the whole research area (proportion of 1), and the combined END_AM index is 0.129, and the combined MED_AM ist 0.297. When comparing the upland to the lowland areas, one sees the difference in e.g. END_AM between the two topographic regions (0.127 to 0.133).

5.2.2.3 Landscape matrix analysis

Landscape matrix analyses are included in the analysis of the research area to allow for a quantitative comparison of landscape structure in different sub-regions of the NRWNNR, especially concerning the introduction of large-scale rubber plantations and their effect on habitat distribution and fragmentation (Opdam et al. 2002). The main tools for this analysis were ArcGIS and FRAGSTATS 3.0 (McGarigal et al. 2002).

The main indices used for an assessment of the research area (and of different sub-catchment within the area) were mean proximity of forest patches (PROX_MN) and connectance of forest patches (CONNECT) as measures for the distribution and connectivity of the most divers land use class. Shannon's Diversity Index (SHDI) and contagion (CONTAG) were assessed to give information about proportional abundance and distribution of land use classes within the research area. In addition, area weighted mean patch fractal dimension (FRAC_MN) was used to gather information about the structural quality and the shape of land use patches (see also Lausch and Herzog 2002). These indices were used to assess sub-regions within the NRWNNR and for the comparison of future land use scenarios. For more detailed information see also Cotter et al., in review.

5.2.3 Increased value of biodiversity: Traditional Chinese Medicine in collective forest

As the fast adoption of rubber cultivation has shown, farmers in the research area are generally open for promising alternatives to traditional farming activities. In order to assess the viability of an innovative farm type for future land use planning, we have derived a TCM based agroforestry system from the field work data gathered during our study. This land use system provides the GAMS model with an alternative to the clearing of secondary forests for agricultural purposes.

5.2.3.1 Traditional Chinese Medicine plants

A resource inventory of non-timber forest products (NTFP) with focus on medicinal plants was conducted in the area. Ethnobotanical and socio-economic interviews were used to identify economically and culturally important NTFPs and get more information on their local uses, processing and management practices (Wang, 2000). Moreover, home gardens were surveyed to identify the important medicinal plants cultivated and transplanted from wild to record empirical knowledge on the cultivation and management of these species. A list of important medicinal plants was developed and a literature survey conducted to gather more information about the integration of TCM plants into agroforestry systems, cultivation practices, ecological and growth needs and market potential (Ghorbani et al. 2011). Based on all information gathered, a short list of species was suggested for designing Traditional Chinese Medicine agroforestry systems in the study area. Collectors of medicinal plants in the study area were interviewed in order to gather data on the annual harvest, economic gains from collection and sale of selected medicinal TCM plants, namely *Paris polyphylla* var. yunnanensis (Franch.) Hand. -Mazz., *Asparagus filicinus* Buch.-Ham. ex D. Don, *Asparagus subscandens* F.T. Wang & S.C. Chen and *Tacca chantrieri* André. Workload, monetary gain and yield estimates were transferred to the GAMS LP model to serve as a further alternative for the decision making processes modeled there.

5.2.3.2 TCM forestry as alternative income source

Interviews with TCM collectors in the selected villages reveal that a villager can earn up to 6000 CNY (650€, March 2011) during a single collection season only from collecting *Asparagus* species. The income gain from medicinal plant collection differs among villages because of the availability of resources around the villages. The average income gain estimated in five selected villages was about 1200 CNY (130€) from collecting *Asparagus* spp., 1150 CNY (125€) from *Paris polyphylla* and 400 CNY (43€) from *Stemona tuberosa*.

To parameterize the TCM agroforestry system, we calculated the average income from TCM, the land share of the TCM which estimated to be ten percent of the collective forest total area and the TCM yield. In addition, we estimated the collection efforts for the TCM agroforestry system. Finally, the

TCM forest was added to the set of model activities. Besides, the TCM forest was included in the utility of village households as long as they consume part of it. The data included the price and collected quantities.

We propose this cultivation system as an example for the feasibility of integrating innovative land use systems into future land use scenarios. The basic principles of this agroforestry system are already in use in the area, and widening this approach would possibly unite the ecological benefits derived from maintaining secondary communal forests relatively close to the villages with the need of the local population to secure their livelihood from a diversified pool of income options.

5.2.4 Erosion control

All throughout the tropics, the conversion of forests to agricultural land on sloping terrain leads to more or less severe erosion. During the establishment of rubber plantations, the extensive clearing of forests and undergrowth vegetation alike exposes the open soil to the heavy rainfall events of the rainy season, leading to severe erosion in the fields and sedimentation in downstream water reservoirs.

The present NabanFrame modelling framework includes the spatially distributed hydrological model AKWA-M®(based on Golf and Luckner 1991; Münch 2004). In recent years AKWA-M has been advanced by Dr. Dittrich & Partner Hydro-Consult GmbH (e.g. Wahren et al. 2007). This water balance and rainfall-run-off model simulates the water balance and flood run-off in watersheds and transforms the different processes from individual sites to a larger area (in ideal cases: catchments). It contains physically based components (run-off generation), which represent the site specific land use conditions in their spatial distribution, as well as a conceptual background (run-off concentration) concerning the geological and hydro-morphological characteristics of a whole river basin or a subcatchment.

Data scarcity limited the model implementation. Climate data series could be used from the Jinghong station, which is located around 25 km in the south of the Naban river basin. For the basin only monthly averages of catchment run-off and precipitation were available. The spatial information on land use, geology, soil, elevation were gathered by the LILAC modellers group (Herrmann and Berkhoff to be published 2011). Facing both the data scarcity and limited space for land use changes in the NRWNNR the simulated differences in catchment water balance between present state and a Business as Usual (BAU) scenario were very small even if site specific changes could be shown (Wahren et al. 2010a,b). These changes were comparable to those described in the literature (e.g. Guardiola-Claramonte et al. 2008). The most distinct changes could be shown for conversion from forest to shifting or permanent farm land. For such a change a high increase of fast run-off (e.g. surface run-off) was simulated which means an increase of erosion. This effect enhances with increasing slope.

For the “Go Green” scenario it was suggested that afforestation measures should be considered in the context of reducing erosion risk locally. Therefore, sites with steep slopes (slope > 30°) are considered as “erosion-risk areas” and were (spatially explicit) transferred to CLUE_Naban.

5.2.5 Lifecycle of a rubber plantation

Data on lifecycle, management and yield distribution of rubber plantations from 66 randomly selected households from four villages (ManDian, PanBing, NaBan and DaNuoYou) located within rubber hosting altitudes was gathered in 2008. The number of plantations owned by households, the

year of establishment and the year of the first harvest were surveyed. More detailed data from NRWNNR plantations covering genotype composition of plantation was gathered in 2009. Rubber yield under a range of variables (age, genotype and site-specific attributes) was investigated.
The information on the proportion of young and productive rubber plantations based on the dominant crop cycling intervals and historical satellite imagines was assessed by the CLUE_Naban model for spatially explicit land use allocation and to the ECOL modelling group for impact assessment on biodiversity.

5.3. Results

The field work and data analyses carried out during our LILAC project yielded a considerable amount of data and scientific insights into the processes and interrelations in our research area. While the disciplinary results are published elsewhere, the authors of this paper focused on using the information obtained to parameterize the storyline for the “Go Green” scenario. The findings of the ecological surveys (5.2.2), the results of the socio-economic assessments (5.2.1, 5.2.3 and 5.2.5), the hydrological impact assessment (5.2.4) and the data from remote sensing and historical land use change analyses were combined to serve as input for the GAMS and CLUE_Naban models. GAMS provided the projected land use demand for the “Go Green” scenario, whereas CLUE_Naban allocated the land use types spatially within the scenario for the year 2025. Some of our interdisciplinary findings are highlighted in the following paragraphs.

5.3.1 Integration of TCM agroforestry into the scenario

The village household programming model GAMS calculated the land use percentage share for rice (*Oryza sativa*), corn (*Zea mays*), tea (*Camellia sinensis*), rubber, vegetable, hemp (*Cannabis sativa*), TCM and collective forest for the time period of 19 years. The model results suggest increasing share of land allocated to collective forest with TCM in comparison with collective forest without TCM (in case of BAU-scenario) in the long run as given in Fig. 5.1a,b. See also Gibreel et al. (to be published 2011), for more information on BAU scenario details.

The impact of TCM production decision on land use can be evaluated through the shadow prices. Obviously, with increased land price, village households respond by shifting their emphasis to the production of the perceived high value crops that yield higher returns to resource use (Gibreel, 2009). The model shows that households behave in different ways to adjust their internal endowments of land in response to the”Go Green” scenario. Results show that the land input has been efficiently utilized and have positive shadow prices or marginal products in case of rice, corn, tea, hemp and TCM (Table 5.4). Conversely, the shadow prices of rubber and vegetable are calculated to be zero, which means it is not rational for the village household to produce rubber and vegetable due to zero marginal returns of land use in the long run. As evidence, the TCM largest shadow price (6071 CNY (660€) per hectare per year) shows the likelihood of the TCM based agroforestry system to be the most profitable land use activity followed by tea in the long term. Consequently, shadow prices of traditional crops like TCM and tea give farmers de facto incentives for conservation. Although preferences may change over time, shadow prices create a buffer for sudden losses of cropping diversity on farmers' fields concerning rice and corn production as explained by their positive marginal products in table 5.4.

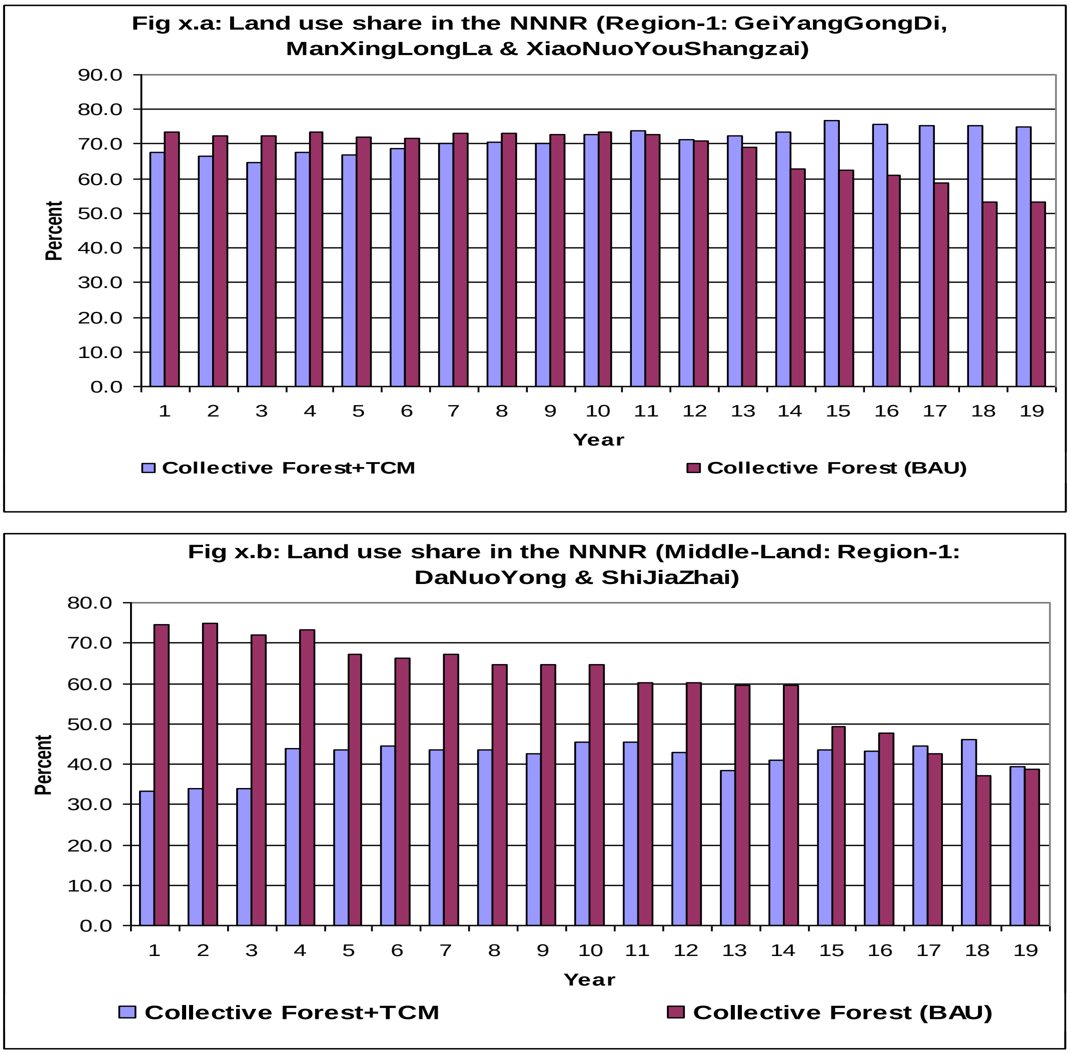


Figure 5.1 Comparing the impact on land use change between the "Go Green" scenario and alternative BaU2025 scenario. Region-1 villages are separated into possible rubber producing (x.b) and non-rubber producing villages (x.a)

Table 5.4 Land shadow price in different land use scenarios (BaU & "Go Green") for the main agricultural activities in NRWNNR. The "0" values in rubber and vegetable represent the farmers' unwillingness to invest into an expansion of these two activities based on the storyline.

	Land Shadow Price (CNY/Hectare/Year)	
	BaU-scenario	Go Green-scenario
Rice	201	372
Corn	219	646
Rubber	13549	0
Tea	2526	1960
Vegetable	355	0
Hemp	1421	1592
TCM	N.A.	6071

5.3.2 Reforestation potential of erosion hot-spots

The NRWNNR is an area with a high morphological energy. About 15 % of the area belongs to the erosion risk areas described in chapter 5.2.4.

Based on the analysis done with the AKWA-M model, we were able to identify 32 ha of farmland under serious erosion risk and redistribute this land to reforestation efforts in CLUE for the present land use distribution. Another 15 ha from the erosion risk category are covered with rubber. The approach for the Go Green scenario was not only to prefer this land for afforestation but also to avoid any conversion of forest on land which belongs to the erosion risk category. Following the rules of the Go Green scenario the farmland with a high erosion risk would reduce to 19 ha (+ 7 ha rubber).

This measure not only reduces the erosion, but also increases connectivity of forest patches by interlinking upland forest areas while providing new habitats for forests based arthropod and plant species. In addition, these reforestations can be used by farmers to establish TCM forest plots.

5.3.3 The dynamics of rubber cultivation

The first small holder rubber plantations within NRWNNR were established in a wave pattern. Oldest plantations in central NRWNNR have been formed in the late 80s mostly on hills at the same approximate elevation as the villages situated within 650 to 700 m a.s.l.. Second wave - which forms not as much a sharp peak - occurred in the mid 90s; and since, establishment of new plantations has been more gradual. Newer developments have taken place in further distance to the village centers and in higher elevations. An about every ten years periodical frost which occurs in this region has somehow set a “trial and error” based elevation limit for plantations.

Rubber trees in the research area are usually harvested for the first time seven years after planting. Rubber yield increases until an age of around 17-18 years, where it reaches maximum values. Afterwards yield steadily decreases until, at an age of between 25-30 years, at this stage farmers are expected to cut down the trees and sell the timber. This lead to the establishment of two rubber age classes for the Go Green scenario: young, economically unproductive rubber plantations up to an age of seven years, and older, fully yielding plantations of between 7 and 25 years.

5.3.4 Evaluation of biodiversity and its’ impact on the scenario storyline

Forests harbor by far the majority of plant species when comparing the land use types within our study area (796 out of 1252, table 5.1). In addition, forests contribute the highest proportion of endemic plants (15%) and the highest numbers of red list species (91 species) and TCM plants (208) to the indices used for the evaluation of NRWNNR (table 5.1). The analysis between upland and lowland regions within the study area shows a lower area weighted index for exotic and invasive species in the uplands compared to the lowlands. This is due to the greater proportion of rubber and forest land use classes in the lowlands. The uplands are dominated by dryland agriculture and tea plantations, which have a low number of endemics but comparably high numbers of exotic and invasive plants (table 5.2).

The assessment of wild bee species shows a strong connection to forest habitats, with species numbers and diversity indicators declining in open land and rubber land use types (table 5.2). Ground beetle diversity is closely related to open land habitats and, to a lesser degree, forest sites. This effect does not show that strong when looking at the area weighted mean indices, as forest land use classes cover a high proportion of the research area (70%), thus adding more weight to the GBI_AM. Nevertheless, the GBI_AM is higher in the upland areas than in the lowlands (16.6 to 14.0), mostly due to a comparable proportion of forest land use classes in both elevation levels with the main differences being the rubber imprint in the lowlands and the spread of dryland agriculture in the uplands. Especially in the lowland areas, the mean proximity (PROX_MN) and connectance (CONNECT) of remaining forest patches within the rubber/agriculture mosaic is low, thus decreasing the chances for insect and plant population interchange and repopulation from nearby forest patches. Contrary to our expectations, we have found a comparably high number of plant species within rubber plantations (518 species) and a low percentage of exotic and invasive species (16% and 14%, respectively). The number of IUCN red list species is highest among anthropogenic land use systems (20 species), and the number of medicinally used plants rivals the amount found in the forest land use types (193 and 208 species).

Dryland and irrigated agriculture as well as tea plantations ranged low in plant species diversity (255, 146 and 124 species, respectively), and did show the highest values in indicators for invasive and exotic plants (table 5.1).

Thus the conservation efforts should focus on the protection of existing forest patches from deforestation and creeping decline, as well as on the establishment of more close-to-nature farm types, e.g. agroforestry or the discussed TCM forests. These farm types can help to decrease the pressure on protected forests and, at the same time, offer more niches and habitats for insects and tropical forest plants than comparable agricultural land use classes.

5.3.5 Integration into GAMS and CLUE

Our mathematical programming approach is dynamic. It allows us a determination of an optimal allocation of land, labor and capital, given a set of goals and constraints on land, labor and capital availability. The model was applied to describe the relationship between policy change and land use decision making of the household in the NRWNNR. Its features are as follows: first, the model is designed to maximize net income, simultaneously incorporating farm and off-farm activities, subject to constraints on land, labor and capital resources. Land use activities are constituted by annual cropping activities (rice, corn, hemp and vegetable), perennial tree production (mature rubber and mature tea), TCM and fallow. Food expenditures stem from self-consumption of farm products and food purchased. Food expenditure decisions are based upon linear consumption choices that combine quantity with prices of food products under the constraints of basic requirement of food preference of the households. At the optimal solution of the model we were able to calculate land demand as percentage share at the average village household for each crop activity as derived by price and yield parameters. The calculated percentage share of land demand of each land use class was transferred to CLUE-Naban for mapping land use change (see table 5.5).

Table 5.5 Percentages of land use classes in NRWNNR in 2006/2007 and in the proposed "Go Green" scenario. Total might not add up properly due to rounding for easier presentation.

	Land Use Classes in NRWNNR		
Land Use class	Land Use 2006/2007 (% total)	Go Green scenario (% total)	Change
Rainfed	15.3	10.9	-1200 ha
Irrigated	3.0	2.4	-160 ha
Rubber	9.5	6.3	- 860 ha
Tea	2.2	2.3	+27 ha
Hemp	0	0.4	+ 130 ha
Collective forest	15.2	20.0	+ 1300 ha
State forest	54.6	57.3	+ 730 ha
Total	100	100	

Based on the concept of combining empirically quantified relations between land use and its driving factors with the site-specific modeling of competition between land use classes based on, among others, location suitability, neighbourhood relationships and conversion elasticity, CLUE_Naban is able to spatially allocate the future land use demands from GAMS modeling process. Factors influencing the iterative distribution process and the resulting land use patterns are e.g. the distance to the next village, river or road, the elevation and exposition, or the availability of labour per hectare. For more detailed information, see Berkhoff et al. (to be published 2012) and Verburg et al. 2006.

The erosion-risk areas have been designated to be put out of agricultural use, leaving them for natural succession or afforestation. State-owned forest land was put under stricter conservation laws, ensuring that existing natural forests would be exempt from land use allocation.

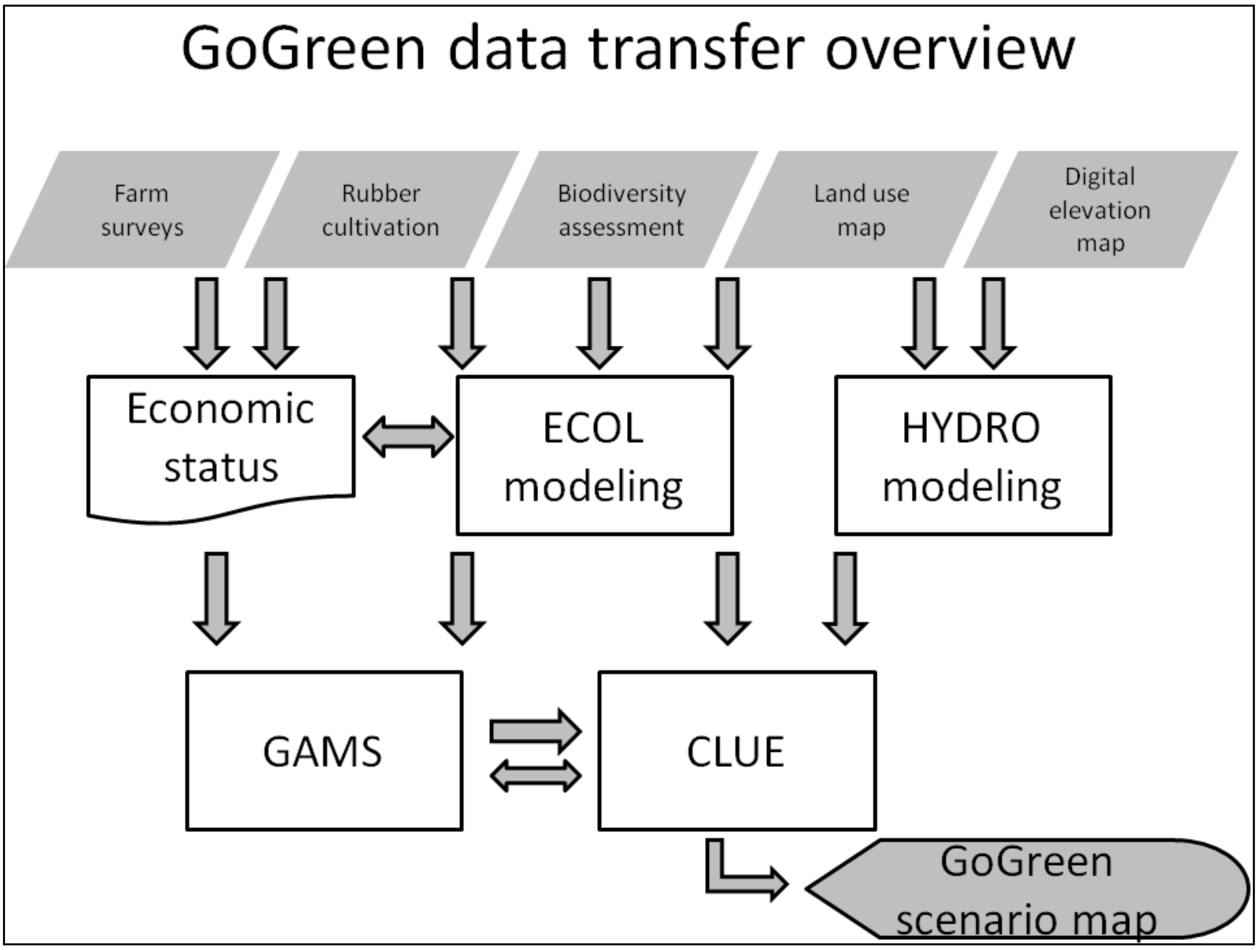
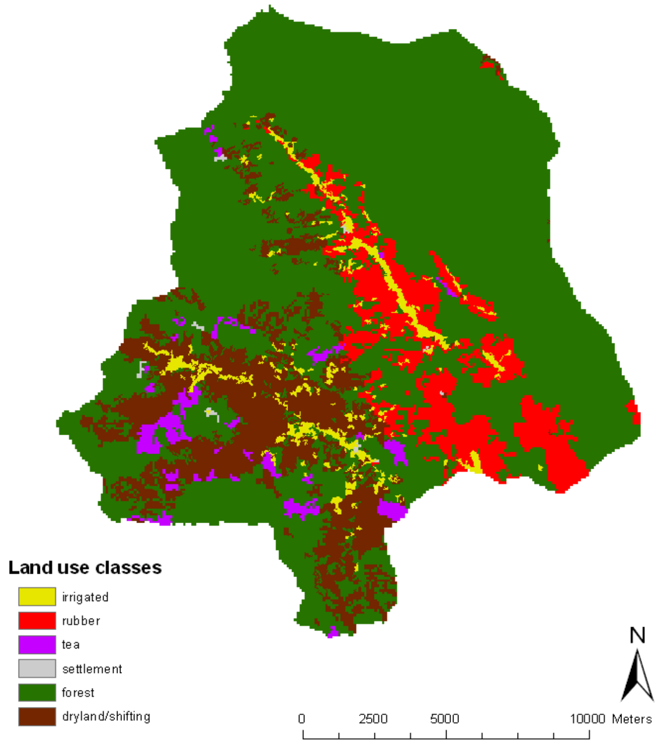


Figure 5.2 Go Green scenario parameterization data transfer. Field work data from surveys and collections is combined with remote sensing data to serve as basis for the analysis of the current situation and the assessment of Go Green scenario parameters. Information is then being transferred to GAMS and CLUE models for computation of land use demand and land use distribution.



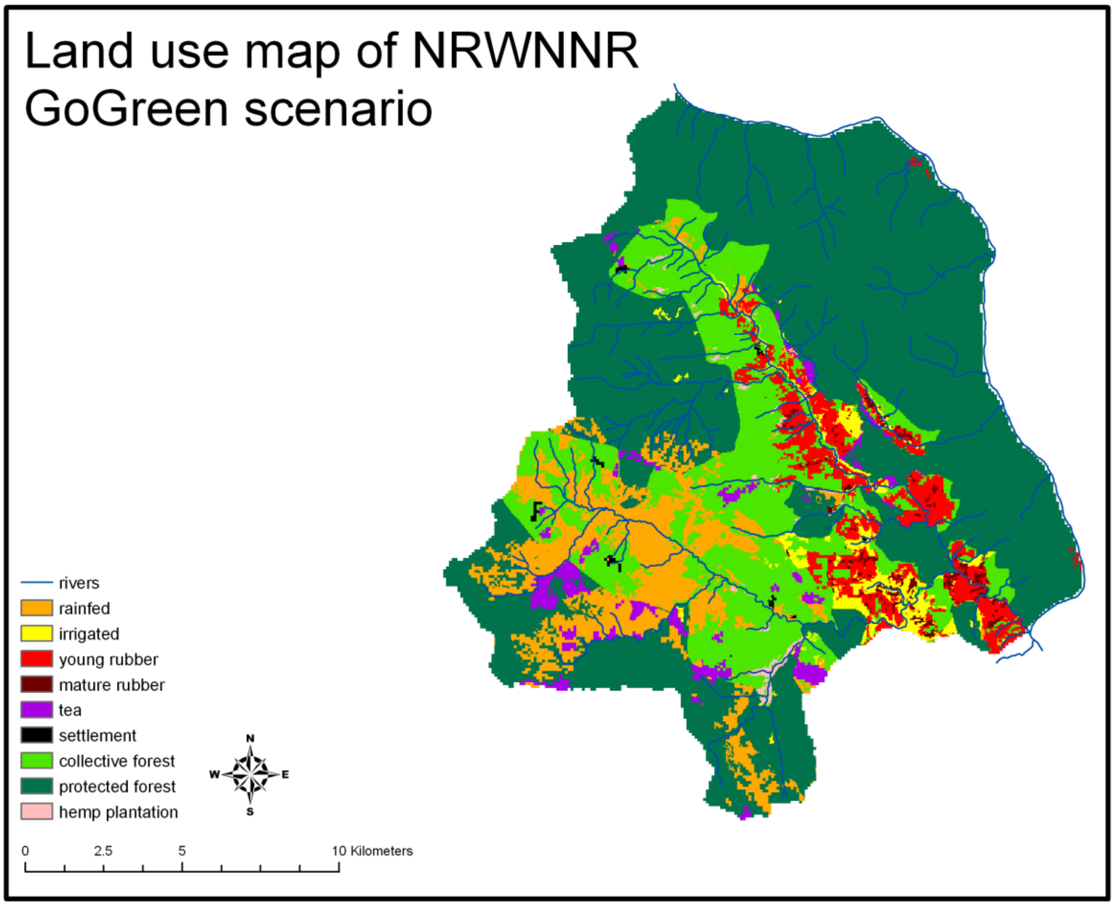


Figure 5.3 Current land use map of the Naban River National Nature reserve in comparison to the "Go Green" scenario map as final result of GAMS land use demand modeling and CLUE_Naban spatial distribution.

Nuppenau (2008) stated that: "Since our aim is to accommodate nature (i.e. species) in a cultural landscape of multiple farmers, a question is how to receive a depiction of a suitable landscape for biodiversity conservation?" He added: "Ecologist play the role of a mediator having own interests. As an analogy, ecologists can be considered brokers who plan and trade services, though they are not neutral and need money. Therefore, to create conditions that are favorable for the desired species prevalence certain measures should be taken. The method used is basically composed of a shadow price analysis and compensation cost "willingness to accept". Therefore, understanding behavior of the village households has implications for the on-farm conservation of this diversity. According to Sydara (2007), economic models of land allocation may lead to expectations for village households' response that "unexpectedly" do not become visible, if market prices fail to reflect the value of their product. We conclude that shadow prices explain land allocation better than market prices.

5.4 Discussion

Using the methodology presented in this article, we have been able to parameterize the storyline for the Go Green scenario in order to allow for the modeling of a scientifically sound scenario for sustainable land management in our research area. While we were able to use data from field work and literature for most of this process, there were some assumptions that had to be based on scientific extrapolations and expert knowledge of the research area. Most of these dealt with the acceptance of innovative approaches by local farmers (rubber, TCM) or with the probable development of regional and international market demand as in the case of rubber prices. As preparation for the parameterization of social datasets (not discussed in detail here), we were able to assess the adaptation speed of rubber cultivation based on surveys and historical data, and thus were able to identify villages that have been faster to adopt opportunities. These and similar information served guideline for the prediction of farmers' decision making in the scenarios (Berkhoff et al., to be published 2012).

5.4.1 Coupling disciplinary models into interdisciplinary scenario designs

Scenario storylines typically deal with drastic land use changes (complete afforestation, clear cuts etc.). These extreme assumptions show potentials or worst cases and give a range of future perspectives. For decision making it is hard to evaluate such results, especially when parties with competing interests discuss the results controversial.

The methodology presented in this article has proven to be very useful when trying to combine the needs of environmental conservation with socio-economic demands of the people living within an area. With the results from the ecological evaluation we were able to not only identify land use types of special interest for conservation and rural livelihood through the provision of habitat for rare or medicinal plants, but also to identify areas where the spatial coherence of available habitats was threatened by ongoing land use change. The interlinking of the proposed activities to secure the future stability of natural forests and the services provided by them with the novel land use activities introduced via TCM-agroforestry in secondary and threatened community forests and reforestation on erosion prone agricultural areas has been well integrated into the modeling framework for land use demand and distribution.

An integrated approach as presented here does not only make the future scenarios more realistic but also gives the modeler a closer range of the variable future land use and makes the results more trustworthy.

Similar approaches could be used to assess land use change scenarios all throughout the Greater Mekong sub region, where a multitude of rural communities and nature reserves face similar challenges as the NRWNNR. The ecological and socio-economic datasets and models needed for these approaches can be adapted and extended to cover the particular situation in e.g. Northern Thailand or the rubber growing areas of Cambodia. Remote sensing data and digital elevation models are widely available for free or with only manageable monetary commitment needed (which in many cases can be provided by international non-governmental agencies.)

The presented methodology is not restricted to rubber cultivation alone. Similar situations exist in many countries of the Malayan Archipelago confronted with the expansion of oil palm (*Elaeis guineensis*) plantations into natural and peat forests (Germer and Sauerborn 2008).Further in Western and Central Africa with the spreading of small holder renewable energy plantations or the gradual decline in forest cover in the Amazon basin caused by subsistence farmers following the tracks of commercial forestry enterprises.

5.4.2 Feasibility and workload of the scenario design process

Admittedly the workload leading to the datasets used for the different models was considerable. Over the course of three years more than 15 partner institutions from China and Germany were involved in the field work gathering ecological and socio-economic data, acquiring and assessing remote sensing information and sources on land use policy and history, as well as analyzing the social situation in the research area and, finally, transferring these information into GIS based datasets compatible with the modeling tools used for this article. The process was accompanied by regular national and international workshops between scientist, local experts and nature park administration alike.

Nevertheless, when considering this or similar scenario design processes for other research areas, many of the concepts and data-transfer steps presented here will prove useful to facilitate future work plans and to guide efforts for improved performance. In addition many of the datasets on the socio-economic situation or the species diversity already exist for a multitude of nature reserves or areas of heightened scientific interest.

5.4.3 High species diversity in rubber

Although the two age classes in rubber vary in plant and animal species composition, both growth stages are still relatively rich in plant and arthropod species due to the close proximity of natural forests and the relative short time after the initial transformation from forest to plantation. Young rubber plantations show a strong influence of open land or bushland related grass and shrub vegetation with individual remnants or saplings of forest tree and undergrowth species leading to a relatively high species diversity and proportion of endemic plants. In older rubber plantations, successive years of weeding and the closure of the rubber canopy result in a shift towards shade tolerant undergrowth species originating from the formerly forest soil seed bank and from seed dispersal of nearby forests with still remarkably high numbers in species diversity and endemism. We expect species diversity to rapidly decline after a rubber plantation is being replaced by another consecutive plantation as soil seed banks and rootstocks are depleted.

5.4.4 Traditional Chinese Medicine and agroforestry

Cultivation of medicinal plants as TCM agroforestry system is an option to reduce pressure from wild populations of medicinal plants and protect the species as well as providing steady supply of plant material and secure income for farmers among others. These systems could help to preserve the soil and protect from erosion. There are examples of agroforestry systems in Yunnan province in which medicinal plants are the main components. Cultivation of *Amomum willosum* in secondary forests is an example (Liu et al. 2006). However, nowadays because of the low market prices *Amomum* cultivation is abandoned. The proposed TCM agroforestry system should consider diversification of products to buffer the future fluctuations in the demand and price of some medicinal species. In general this system could work very well in sloping terrain and combination of this practice with the Chinese government program for the conversion of sloping land could provide incentives for the farmer in the early years of system establishment and also could protect soils from erosion in sloping lands. The TCM agroforestry system would help to conserve the wild populations of medicinal plants and provide villagers not only additional cash income but also many other indirect or non-monetary services. These indirect benefits should also be integrated, together with more detailed information on physiological and agronomical aspects of the selected TCM plants, into future modeling approaches to improve the overall effectiveness of these models.

When considering the introduction of new agroforestry systems with TCM plants as main components, the main issue of concern is lack of ecological data on the target species. Traditional knowledge could help to some degree to overcome this problem. Nevertheless our proposed TCM agroforest has so far not been established in the research area, but the outcomes of the modeling approaches presented here point towards the economic possibility of this land use type. The initiative of future research and extension work is needed here to establish these systems on trial sites.

5.5 Conclusion

The method presented here enabled us to integrate multiple disciplinary models and approaches into the parameterization and design processes of land use scenarios which led to a much more detailed and optimized storyline, as can be seen in the results part of this article. By combining the available information and datasets into the planning process and closely interlinking the assessments of the different workgroups we were able to evaluate the impacts and outcomes of future possible land use decision on the research area's economic, ecological and hydrologic situation even throughout the scenario design process. With the procedure introduced we were able to frame a Go Green scenario for the NRWNNR that combines:

1. The protection of nature reserve forest land use types that have been shown to harbor the greatest diversity of rare and endemic species in the research area.
2. The retirement of unsuitable agricultural activity on high risk farmland prone to erosion.
3. The feasibility of the introduction of TCM agroforestry and its projected acceptance by local farmers as alternative to monoculture hemp, tea or rubber cultivation.

Not only did the final modeling of future land use scenarios benefit from this interdisciplinary approach, but also the scientists from every single discipline involved profited through the communication of intermediate results within the research framework. These regular feedbacks allowed for a greater reliability of the disciplinary models, but also for more reasonable approaches towards scenario design and subject area specific objectives. The constant interchange between the specializations helped to avoid mistakes by neglecting influences from aspects which are typically not considered in the isolated discipline (e.g. for hydrology – economic considerations and social behavior).

During the application of this methodology we had to cope with the problem of data scarcity regularly, especially concerning data from sources other than the involved disciplines. Adapting this procedure to other or more closely observed research areas and integrating possible middle-term effects of climate change will lead to additional advancements and extensions that improve the quality and reliability of the design process for future alternative land use scenarios.

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6. Acceptance of 3D-visualization techniques in Nature Reserve planning – a case study from southwest China

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Outline and overview

The acceptance and comprehensibility of computer based 3D visualization models for the communication of possible future land use scenarios has been tested in chapter six. Two alternative scenarios, closely linked to the ones presented in chapter four and five have been visualized and compared to the status quo, with questionnaires and guided interviews covering the acceptability and adaptability of such techniques for professionals from various fields of nature conservation.

Acceptance of 3D-visualization techniques in Nature Reserve planning – a case study from southwest China

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Abstract

This article examines the fortes and flaws of landscape visualizations and ascertains their role in nature conservation, sustainable land use, environmental decision-making and management. Integral parts of this study are the designing of two alternative future scenarios for landscape visualizations (by 3-D visualization techniques) in environmental decision making and to collect experts´ reviews and comments for its applicability to environmental research and management. A highly biodiverse region of southwest China (Naban River Watershed National Nature Reserve (NRWNNR); Xishuangbanna, PR China) was selected as role model as biodiversity of this area is seriously threatened due to a constant spread of monoculture rubber plantations. After constructing 3D computer models for the present situation and alternative visualized scenarios for future land use of this area, a multinational survey was conducted to seek the opinion of environmental professionals to asess the utility of visualizations. The findings of the survey showed that visualizations attempting to look into the future by projecting alternative scenarios can substantially enhance awareness to certain important issues of nature conservation and environmental protection and thus may help facilitate environmental decision making from the individual to societal levels. The knowledge base formed through survey with international participants throws light on the capabilities and limitations of landscape visualizations and suggests opportunities for developments. Overall the significance of visualization techniques is well assessed with viewers regarding them as “comprehensible”, “meaningful” and “expressive” tools for communication and the importance of visualizations is well recognized for integrating them into environmental management system.

Keywords: NATURE CONSERVATION, 3-D VISUALIZATION TECHNIQUES, LANDSCAPE VISUALIZATIONS, ENVIRONMENTAL PLANNING, SCENARIOS

6.1 Introduction

Nature conservation (especially in the tropics) through land use planning is simultaneously influenced by natural as well as socio-economic environments. Planning instruments are necessary to assess the consequences of possible land use changes for environment and society alike. For environmental planning, two dimensional maps following the standard principles of cartographical design have been used traditionally for providing spatial information (Blaschke, 2005; Naidoo et al., 2008; Osborne et al., 2001; Phua and Minowa, 2005; Pettit et al., 2011). Landscape visualizations using three dimensional modeling is emerging as a significant research element to depict environmental impacts of both location specific developments (e.g. a reforestation program) and more widespread environmental changes (e.g. climate change). Landscape visualizations which are used to communicate existing conditions and alternative landscape scenarios, past and present for both educative and consultative purposes (Priestnall and Hampson, 2008) can bring large data sets to life and enable people to become part of an interactive decision-making process (Stock et al., 2008; Pettit et al., 2011).

Recent studies have emphasized the importance of using visualizations to establish communication between planners, clients and public to discuss visual impacts on the landscapes (Lange, 1994; Sheppard, 2005; Lovett et al., 2009) and many researchers have created past, present, future scenarios or alternative land use scenarios (Bishop and Lange, 2005; Lovett, 2005, Pettit et al., 2006) and conducted regional surveys (Tress and Tress, 2003; Appleton and Lovett, 2003, Appleton and Lovett, 2005) or nationwide surveys (Paar, 2006) to investigate the role and use of visualizations for environmental planning. However there are still many challenges to prove visualizations as a fool-proof system of communication and environmental decision making. After conducting a nation-wide survey on landscape visualizations in Germany, Paar (2006) stressed the need of more surveys on landscape visualizations with an international focus in mind. This study aims at seeking the opinion of international environmental professionals through semi-structured interviews and internet based survey using a structured questionnaire with visualized scenarios in order to assess the viability and limitations of visualization techniques.

This study was conducted within the framework of the project “Living Landscapes China”-(LILAC), a sino-german collaborative research project. The research site, the Naban River Watershed National Nature Reserve (NRWNNR), Xishuangbanna prefecture of Yunnan province of China covers around 27100 ha of land. The region is one of the biodiversity hotspot regions of the world (Myers et al. 2010) and was considered suitable for assessing the soundness of participatory landscape-based conservation mainly because this region has undergone considerable land use changes, mostly due to a constant spread of rubber (*Hevea brasiliensis)* cultivation resulting in deforestation of highly diverse lowland rainforests. Li et al. (2007) reported that the forest cover in Xishuangbanna has been reduced from ca. 70% in 1976 to less than 50% by year 2003, the important driver of land use/land cover change in this region being the transformation of tropical forests to rubber plantations. The drastic increase in the area dedicated to monoculture rubber plantations is not only damaging forests and deteriorating traditional land use but is also threatening biodiversity and causing an adverse impact on ecosystem services and environment (Wu et al., 2001; Zhu et al., 2005).

6.2 Material & Methods

6.2.1 Scenario development

On the basis of administrative, topographic and land use data sets the research area scenarios for present and alternative future land use distributions were created using Visual Nature Studio-2 (VNS-2) software from 3-D Nature World Construction Set (WCS), Adobe Photoshop CS3 and ArcGIS from ESRI. For this purpose an IKONOS-derived land-cover map of the research area compromising the eight main land use classes (LUC) served as the spatial base for scenario construction.

The present scenario was created by importing the .tiff file of the land use map obtained from IKONOS into VNS to delineate clearly identifiable eight different LUC which were added in the ecosystem editor of VNS. Digital photography of rubber and various other local trees species were processed and added to the component gallery. Scenes of the present landscape scenario for three locations upstream, downstream and west highlands were generated. This relatively frank method was used to mimic the time constrains and often patchy data availability when implementing visualization techniques as add-on to research or administrative projects that actually cover other foci. A certain amount of insecurity in designing the alternative scenarios, especially in the context of this study, was inevitable, but presumed to be on an acceptable level.

6.2.2 Alternative scenarios

Lambin et al. (1999) suggest that the length of time over which a prediction is valid is a function of the persistence of the observed phenomena, and land cover change is temporally persistent over 10–15 years intervals. Following that track, two different future scenarios of the research area were made based on different storylines that were contrived with respect to the probable and possible land use changes in NRWNNR in the coming decade.

The “Business as usual” scenario is based on a linear extrapolation of the trends in land use of the last 20 years within the research area, with a continuing spread of rubber cultivation at the expense of natural forests and lowland agriculture. Upland forests are in turn suffering from increasing pressure from agricultural activities that are transferred to areas in higher altitude. The share of rubber cultivation increases from 14 to 25% of the research area and farmland spreads in the higher altitudes where rubber cannot be grown for climatic reasons. Forest cover was estimated to decrease by 10-15%. This information was used to adapt the current land use map to the “rubber boom” scenario, which was then processed and imported into VNS for the visualization of the three scenes already depicted in the present scenario.

In contrast, the “Go Green” has a much more conservation oriented approach. The expansion of conservation zones was assumed to stop deforestation, and the stricter application of conservation laws and regulation would lead to an increased share of grassland and degraded bushland to be replaced by forests or agroforestry either through natural succession or reforestation (increase from 54 to 65%). The re-establishment of riparian forest habitats would help to increase the connectivity between forest reserve patches and facilitate conservation efforts. By combining these conservation efforts with state-of-the-art agroforestry methods focusing on the sustainable production of high-value products, the economic impact of the reduction in rubber growing areas could be compensated. The land use map was adjusted according to these assumptions, and 3 scenes where created using VNS. See a comparison of one of these scenes for all three scenarios in figure 6.1.

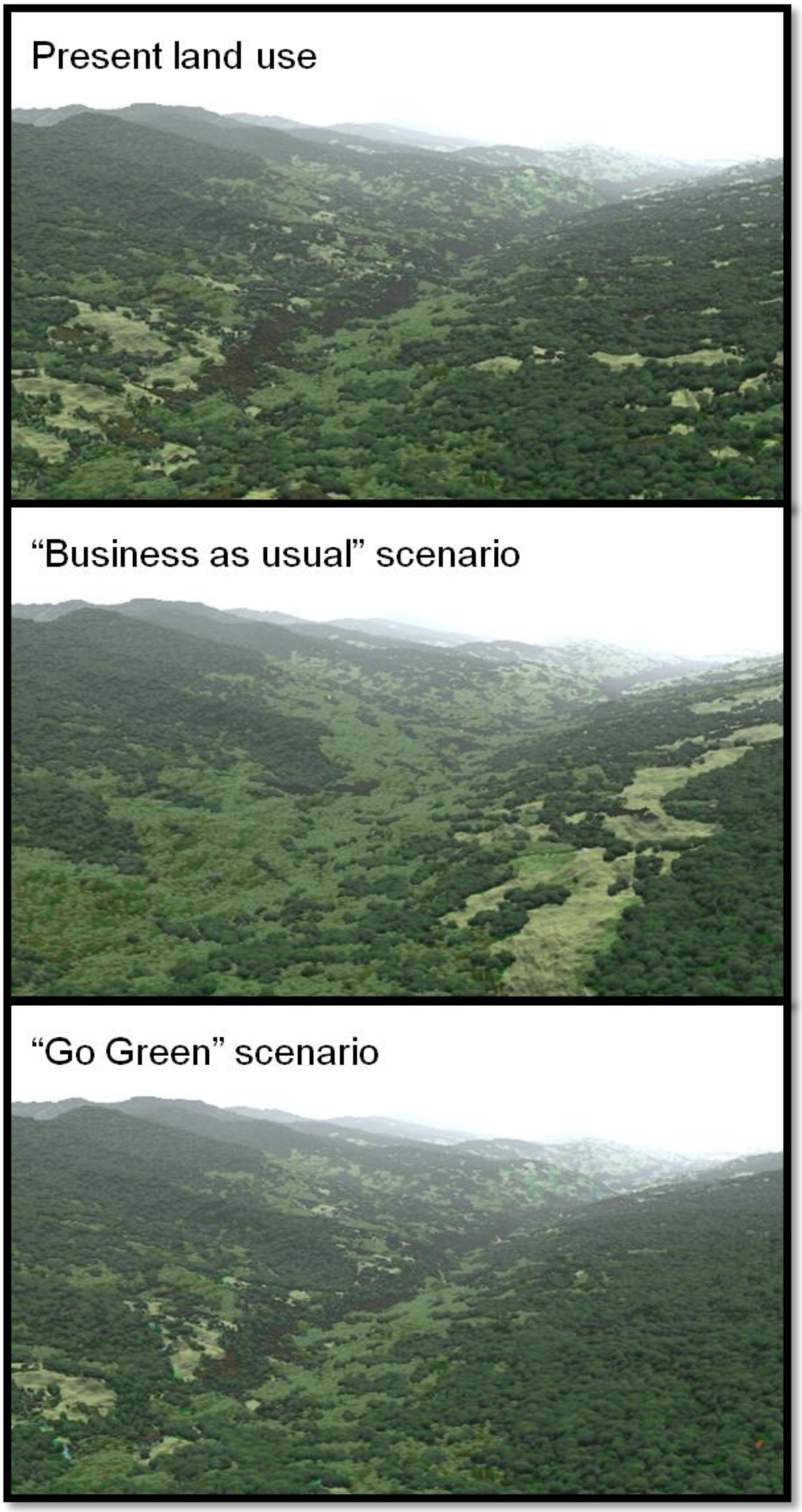

Fig.6.1 Visualization based a) current land use distribution, as well as b) projected rubber intensification (“BaU”) and c) conservation (“Go Green”) scenarios. Dark green areas are natural forests, light green is rubber, yellow-green are agricultural areas (mostly maize), brown are rice paddies. The viewpoint of this visualization is situated above Naban river valley, facing south.

6.2.3 Structured interviews and survey

The second phase comprised of presenting visualized scenarios and conducting structured interviews and survey. In order to get a feedback from broader perspectives, international interviewees were selected from various fields of expertise such as scientists from ecology and agriculture, representatives from NGO´s and administrative personal from nature parks as well as politicians and professionals from landscape planning and conservation. The aim was to develop a necessary knowledge base to assess the utility of landscape visualizations as an aid to environmental decision-making and management process by drawing acumen from professionals of different yet related fields of work and activities. A total of 211 questionnaires were sent by electronic mail and additionally 20 semi structured personal interviews were held with professionals in research and education, nature conservation organizations and environmental consultancies. The total turn-out rate for the electronic mail based survey was 16.11%.

The questionnaire was developed to elicit the interest for visualizations as communication, public perception and expectation. In the questionnaire, background information and problem statement with research objective was described, visualizations were presented and purpose of scenario construction was explained. In elicitation questions, the knowledge and attitude of the respondents towards application of landscape simulations, their assessment about constructed scenarios and general evaluation about visualizations, their preferences, opinions and comments were surveyed. The questionnaire also dealt with price issue and potential future demand of visualization techniques.

6.3 Results

The age bracket of the interviewees was from 26 – 65 years. The average age of the respondents was 41 years, the work experience of the interviewees varied from 1-30 years. The different scenarios provided and their visualizations where clearly received and comprehensible (97%). 67% of interviewees were already familiar with the idea of using landscape visualization techniques for nature conservation and sustainable land use . 67% of the respondents were positively willing to implement visualization techniques in their field of work, with 3% were already using them and 21% were not at all willing to adopt them (Fig.6.2).

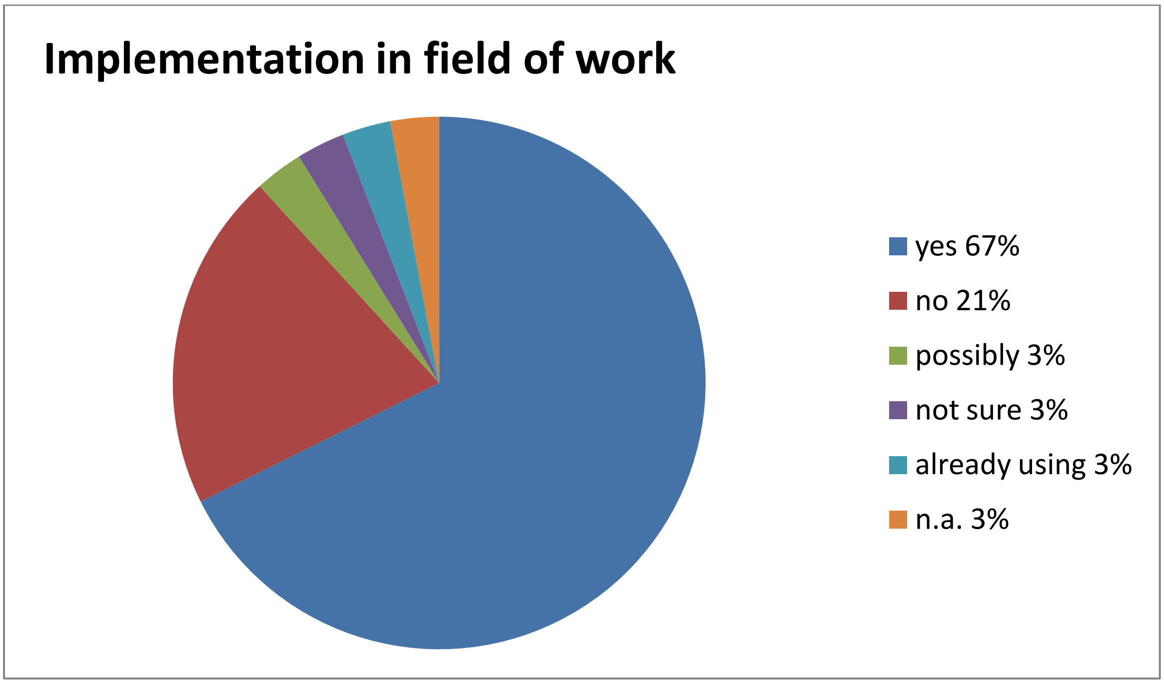

Fig. 6.2 Willingness of participants to implement 3D-visualizations in their respective fields of work

Table 6.1 Opinion of participants about the appropriateness of 3D-visualizations as a means of communication with laymen, community organizations, colleagues and supervisors from their work environment or funding bodies.

Target audience for 3D visualizations	Appropriate tool for communication
Laymen	82%
Community organizations	85%
Colleagues	58%
Senior supervisors	41%
Funding bodies/Government bodies	76%

Majority of the respondents were enthusiastic for adopting visualizations as a means of communication. Table 6.1 shows that community organizations were at highest preference order (85%) with whom interviewees liked to communicate through visualizations followed by laymen (82%) and funding bodies or government bodies (76%).

There was a definitive selection of causes among respondents for choosing reasons for using visualizations as a means of communication. 62% of interviewees agreed to choose 3-D visualizations because of their better expressiveness, comprehensibility and meaningfulness (Table 6.2).

Table 6.2 Reasons for choosing 3D-visualizations above other means of communication given by the studies respondents.

Reasons for implementing 3D visualizations	Percentage
They are more impressive	47%
They are new and unique medium of communication	20%
They are more expressive than others	62%
They are more presentable	53%
They are more convenient than others	3%
They are more comprehensible and meaningful than others	62%

There was almost unanimous response regarding their inconvenience to use.
55% of respondents answered “good”, 18% “ just OK” and 27% “excellent” when answered about the usefulness of such visualizations as medium of communication and as effective tool for nature conservation (Table 6.3).

Table 6.3 Respondents’ assessment of the quality of the 3-D visualization techniques as medium of communication for land use planning and nature conservation.

Grade for the acceptance of 3D visualization	
Poor	0%
Just OK	18%
Good	55%
Excellent	27%

The survey participants were asked about the applicability of visualization techniques in communication for their respective field of work, with a clear preference for using visualization techniques when communicating to laymen or community organizations.
The survey participants contributed with their appraisement and rated the importance of 3-D visualization techniques according to their own viewpoints. The findings of the survey indicated changing attitudes towards visualization techniques as applied to different arenas. 24% respondents feel that implementation of 3-D visualization techniques in scientific projects is not important at all. But they do admit its significance in creating awareness for nature conservation among the public as 59% of them say they are important and 41% think they are very important for facilitating awareness among laypersons towards conservation. 56% agree that they are important for the concept of communication for sustainable land use and planning. And 62% believe that 3-D visualizations are a very important tool for making a comparison of present, past and future scenarios.
A consistently important element to observe is that respondents have altogether a good impression about visualization techniques as 53% assessed them good and 27% rated them as excellent medium for communication. Participants’ responses were quite affirmative and supportive while rating the importance of visualization techniques for the described elements. 100% of respondents agreed with

the caliber of 3-D visualization techniques for creating awareness for nature conservation among public (Fig. 6.3)

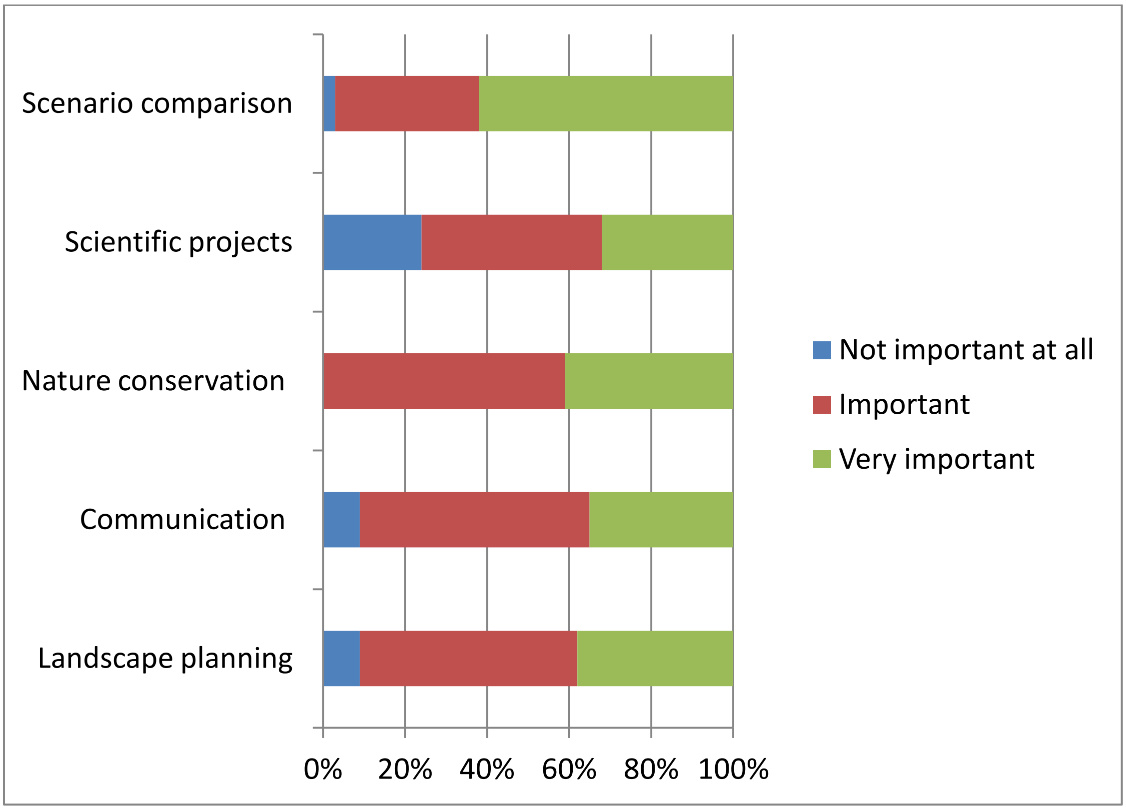

Fig.6.3 Different branches and the respective importance of 3-D visualization techniques stated by the respondents.

6.4 Discussion

Although 67% of the respondents stated their willingness to adopt visualization techniques, not everyone who stated familiarity with the topic was willing to adopt it, mainly for reasons of lack of technical expertise, cost or user's inconvenience (only 3% named it a convenient tool). From a critical point of view, developing visualizations is equally important as applying them. In order to get a good decision from stakeholders, good information is demanded which in turn depends on the quality and recentness of data fed into the system for generating 3-D visualizations. Appleton and Lovett (2005) have also stressed that careful thought needs to be taken for defining an appropriate level of realism before the creation of visualizations and the potential negative effects of increased realism should be borne in mind. Furthermore, 3-D visualizations would be as good and accurate as the quality and meticulousness of data that is used to build the model. Some interpretation of images is always required. It will also be necessary to clarify that even the best visualizations can only be a rough proxy and will not exactly mirror the future landscape.

Paar (2006) points out that so far there has been no academic discussion of "sufficient" "visual biodiversity" of plant species in landscape simulations and that there is still a lack of available plant models for natural landscapes. Generally increased level of details helps greatly to relate to visualizations and evidences are there that increasing details can improve results at any stage. On the other hand, information overloading should always be avoided to keep in track with the concerned issue. Previous researchers like Lange (1999) have also emphasized the "abstraction of information".

Appleton and Lovett (2005) have suggested that increases in details should be tied to real-world data and used only to meet a specific need.

Majority of the interviewees also approved their significance for communicating the concept of sustainable land use, landscape planning and assigned them either very important or important tool for a comparison of present, past and future scenarios. However respondents exhibited a polarity of opinions on the issue of signifying the implementation of 3-D visualization techniques in scientific projects. As compared to 76% who graded them either important or very important, a considerable fraction of the interviewees (24%) were of the view that it was “not at all” important to implement them in scientific projects. These differences in opinion might possibly arise from concerns for reliability or validity of simulations due to different viewpoints and expectations. However, all the interviewees had a common viewpoint that visualization is a technique with great potential for communicating issues related to landscape appearance to general public which is a task that is becoming increasingly important for researchers. Another field of application is in development projects. The techniques used for this survey are a powerful tool for displaying the impacts of nature conservation and may dramatically aide an organization in conveying the importance of conservation to funding organizations and stakeholders.

6. 5 Conclusion

The results of this survey suggest that people have altogether a good attitude towards visualizations with viewers regarding them as more “comprehensible”, “meaningful” and “expressive” tools for communication than other conventional means. 3-D visualizations have a high potential of communicating the message of nature conservation and environmental protection as well as integrating them into environmental decision-making and management processes. However visualization techniques are not extensively used because of their inconvenience, technical know-how needed to operate them and sometimes the factor of reliability and validity also creeps in. Many factors may affect the validity and reliability of visualization techniques such as the lack of secondary information, low realistic representation and different perceptions of people.

Use of visualization techniques is impeded by convenience issue, related cost factor and is dependent on operating proficiency and profession. The conventional ways of communication such as written reports, oral presentations, tables and figures are highly in practice due to their familiarity, easy accessibility, and longer history of usage than visualizations. Nevertheless, participants are inclined to adopt 3-D visualization techniques, to get trained in these and also to pay for visualization services. Survey results show that visualizations are seen as medium of communication with laymen, community organizations and funding bodies or governmental organizations. But the visualization construction and presentation style should vary according to the targeted audience. For scientific community they should always be supported with detailed data structure and for laymen with subsidiary explanations. Imaging is a tool to be used in combination with explanation. This not only leads to the accuracy and validity of visualized models but also enhances public interest and involvement.

The significance of 3- D visualization techniques is well recognized in terms of their applications in generating and comparing alternative future scenarios for land usage and landscape planning. However their implementation in scientific projects seems to be questionable. Visualization techniques should be carefully evaluated and sensibly implemented with regard to the requirements of the project in question. An up-to-date quality data set based on physical and environmental characteristics along with socio-economic variables should be included as scientists might be very critical towards such approaches.

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7. General Discussion

The expansion of rubber cultivation in mainland South-East Asia has had an immense impact on the landscapes especially in the lowland areas, where climatic conditions are favorable for rubber production. In the Greater Mekong Subregion (GMS), rubber plantations have replaced traditional farming systems and valuable lowland rainforests alike. This development is posing a threat to many native and endemic plant and animal species living in the Indo-Burmese hot spot of biodiversity as their habitats are gradually disappearing at an alarming rate. Conservation efforts by the various governments of the GMS are trying to reduce the impact of these developments, but further research on the scale, degree and possible mitigation measures of biodiversity loss is urgently needed. Already now, the confinement of larger species such as the Gaur (*Bos gaurus*), the Asian elephant (*Elephas maximus*) or the Indochinese tiger (*Panthera tigris corbetti*) to relatively small protected areas is putting increasing pressure on the remaining populations.

As Li et al. (2007, see chapter four) have shown on the example of Xishuangbanna prefecture in Yunnan, total forest cover decreased from 70% in 1976 to less than 50% in 2003. This highlights that rubber cultivation is not only directly affecting the distribution of highly diverse seasonal tropical rainforests (reduced by 67%) through deforestation for the establishment of plantations, but also causes second-degree effects since traditional agriculture has to migrate to marginal upland areas, where evergreen broadleaf forests and tropical montane rainforest are replaced. As has been shown in chapter four species diversity is greatly reduced by the transformation from natural forests into managed plantation systems. The research area, for which the presented methods were developed, represents an example of the trends in land use change happening similarly all throughout the GMS. Rubber farming is driving a block of nearly uniform vegetation into the lower reaches of the Naban valley, replacing traditional land use systems and severing remaining habitat corridors and connections between protected patches of lowland rainforest. This in turn greatly reduces the long term chances for survival of protected species within the forest fragments. Above 1000 meters, the first traces of rubber cultivation can be found in seedling nurseries, where farmers are trying to adapt varieties to the cold spells often experienced in the uplands during the dry seasons. Land use in the uplands is mostly dominated by agricultural (maize, rice, hemp) and grazing activities, whose expansions are putting increased pressure on the forest vegetation types. The results from chapter four stress the notion that these different forest vegetation types should be the focus and centerpieces of tropical conservation efforts in the GMS. Here, the by far highest numbers of endemic and endangered plant species are found and they offer the habitat for a plethora of endemic insect, bird and mammal species alike.

The studies reviewed in chapter two suggest the feasibility of alternative rubber cultivation methods (e.g. jungle rubber) that have a less devastating impact on forest wildlife than the common rubber plantations. In our research area, however, monocropping of rubber was the norm, with only singular events of tea intercropping taking place. In addition, a method for the projection of regionally adapted carbon capture properties of rubber cultivation under suboptimal growth conditions was presented and a comparative assessment of greenhouse gas emissions during the establishment of rubber plantations in regard to the preexisting vegetation was conducted. By interpolating available data on biomass and rubber yield from research areas of similar climatic conditions and management practices with data on biomass and vegetation characteristics from our own research area, it was possible to estimate the carbon capture, storage and emission potentials of rubber plantations in Xishuangbanna.

The methodology presented in chapter four has been tested with an array of possible present and future land use maps (see some in figure 7.1). It was possible not only to evaluate the different land use classes within and their distribution throughout the research area, but we were also able to compare distinct sub-regions based on topography or administrative status. One of the aims was to highlight and relate the different challenges stakeholders and nature conservation face in the different elevation zones of Nabanhe to the findings of our partner workgroups from economy and social sciences.

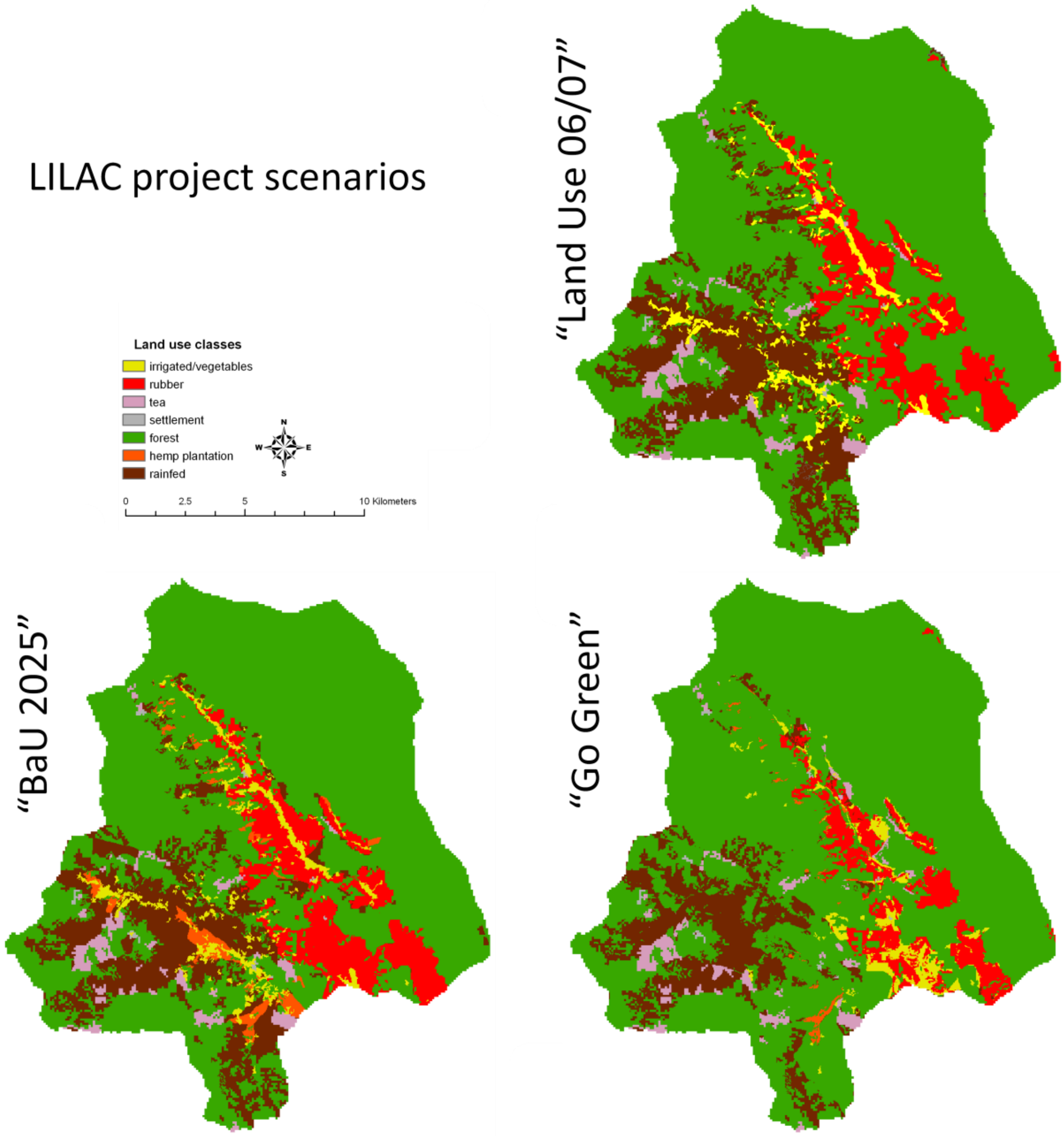

Figure 7.1 Comparison of the LILAC project's land use maps for 2006/2007 (Land Use 06/07, top) and the projected business as usual scenario 2025 (BaU 2025, left) as well as the "Go Green" scenario map (right). The differences in distribution of "forest", "rubber", "rainfed" and "irrigated/vegetables" between the different scenario maps can clearly be seen.

By comparing the impact of possible future land use scenarios derived from earlier stages of our scenario design approach it was possible to demonstrate the applicability and relative ease of use for this evaluation method. A more detailed analysis of the impacts of the "Go Green" scenario has been shown in chapter five, and a concise exemplary comparison of the impacts of the two final LILAC scenarios on flora diversity indices can be seen in figure 7.2. In this figure, the values of flora diversity indices from the two final LILAC scenarios ("BaU2025" and "Go Green") are compared to the values derived from the analysis of the current land use map ("Land Use 06/07" or baseline). The percentage of change from the baseline map is compared, thus highlighting the differences between the pathways that led to the scenario maps and their effects on species diversity in the research area. As can be seen, the "Go Green" scenario is delivering higher values in the indices representing the proportion of endemic species (END_AM) as well as the indices number of medicinally used plants (MED_AM) and Red List species (RL_AM). The index for the proportion of exotic species (EXO_AM) is lower than the index derived from the "Land Use 06/07" map. Most of these changes can be attributed to the increase in forest land use classes, mainly due to the protection from deforestation but also from the reforestation and TCM agroforestry approaches introduced in the storyline of "Go Green". In contrast, the expansion of rubber plantations and the spreading of hemp plantations in the "BaU2025" scenario has caused the indices for endemic species, red list species and medicinal plants to decrease below their "Land use 06/07" levels, while seeing a minor rise in the indices for invasive and exotic species, both of which are closely related to the spreading of agricultural activities.

During the development process this model has been presented to a variety of audiences, e.g. at international conferences. During one of these presentations, the question arose whether the model might not be biased against "forest" land use classes. The argument was that due to the inclusion of medicinal plants into the assessment of Flora Diversity Indices, the land use classes with stronger anthropogenic influence, where medicinal plants are tolerated or even encouraged might receive a better rating in comparison to natural land use classes, where medicinal plants are part of a diverse community. A similar concern was raised for the Red List species and possible sampling biases due to the complexity of tropical forests and probable insufficient representation of rare forest species in the Red List. Taking these considerations into account, a slight shift in the methodology has occurred, that can be traced back when comparing chapter four (table 4.1) to chapter five (table 5.1). In order to alleviate the bias resulting from the unequal distribution of medicinal and Red List plants the two indices concerned with their diversity have been adjusted to not represent the area weighted proportion of those species, but the area weighted mean diversity of medicinal and Red List species. This adjustment enabled the model to still reliably predict the impact of land use change on species diversity within the research area while removing the inherent biases from the culturally biased criteria of medicinal use and Red List. This approach was not followed for the proportion of endemic, invasive and exotic species, as in these cases the information on the proportion of these species was seen more suitable from an ecological point of view than total species numbers by reviewers and commenters.

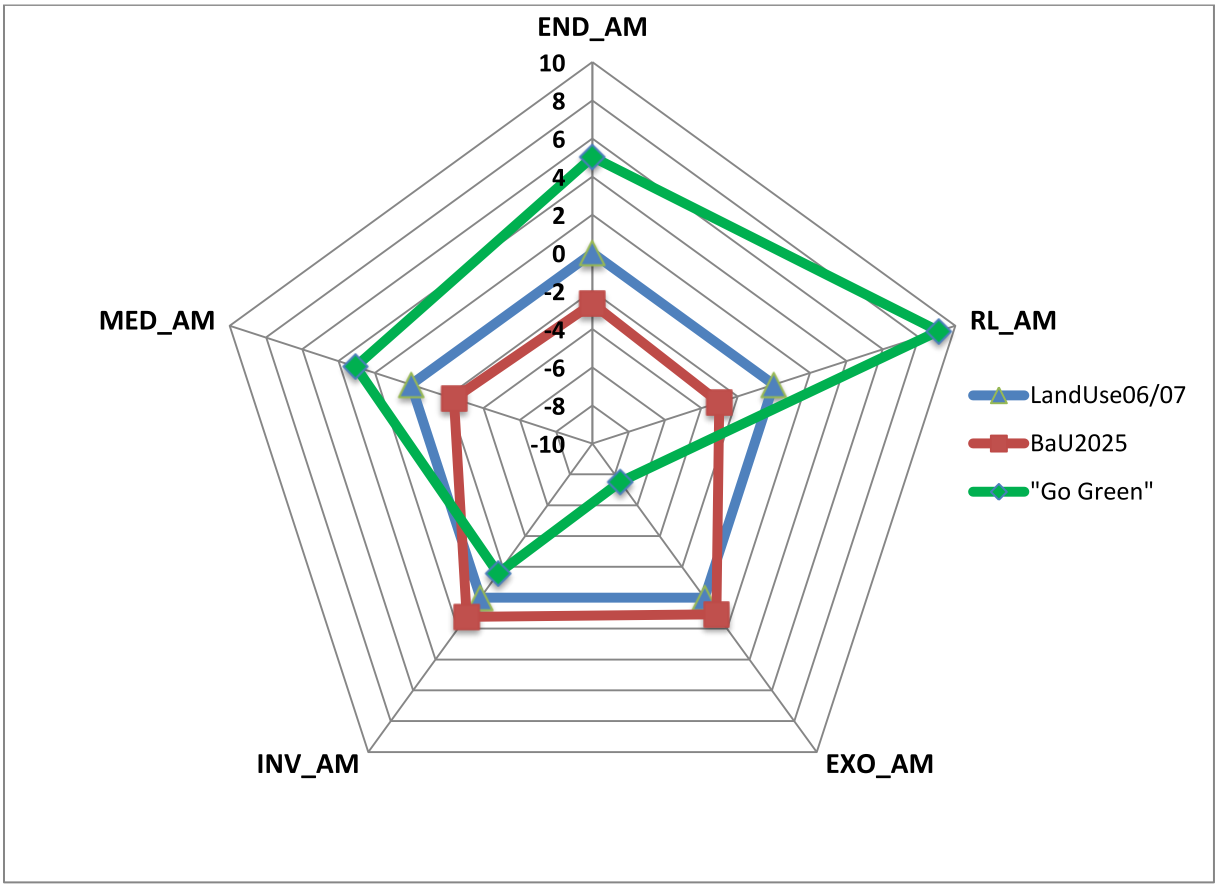

Figure 7.2 Diagram of the changes in Flora Diversity indices of the two scenarios (Business as Usual "BaU 2025" and "Go Green") in relationship to the current land use map (LU06), given as percentages. Note e.g. the differences concerning the Red List index RL_AM increasing in the "Go Green" scenario by 9%, but decreasing in the "BaU2025_final" scenario by 3%. Abbreviation used for indices: area weighted mean proportion of endemic (END_AM), exotic (EXO_AM), invasive (INV_AM) species as well as area weighted mean diversity of IUCN Red List species (RL_AM) and species with medicinal use (MED_AM).

The feasibility of this approach especially by administration stuff with limited experiences in ecological modeling was one of the main goals in designing it. Given a reasonable data set on species diversity and distribution within any given tropical research area, this approach would enable planners and nature park administration to quickly project possible consequences on species diversity indices deriving from land use change within their respective region. Using this approach, the importance of natural tropical forests for the maintenance of species diversity in tropical cultivated landscapes has been pointed out.

In 2004, Machado (see chapter four) stated that due to the demand from conservation management, rapid landscape evaluation methods need to be developed that rely on time- and effort-efficient data requirements. In this approach land use classes are ranked between 1 and 10, ranging from lifeless artificial sites (1) to pristine habitats (10), ranking was done following a complex set of prerequisites and descriptive conditions concerning the "naturalness" of the vegetation and the impact of anthropogenic activities. This method provided an overview over the extent of human impact in a given region, and allows for a reasonably fast assessment of its state, but the rough classification of categories does not allow for a detailed analysis of, for example, plant species composition. Pristine ecosystems are the highest category (10), whereas highly diverse, species rich and extensively managed forage or cropping systems that could harbor a multitude of threatened or endemic plants end up in rather low categories.

Trisurat et al. (2010, chapter four) tested the applicability of the GLOBIO3 biodiversity assessment model (Alkemade et al. 2009, chapter four) to land use change assessment in a tropical environment. This model uses relative mean species abundance (MSA: species composition compared to pristine ecosystems in the region) as a proxy for biodiversity. Literature review was supplying the values for MSA, and buffers along the road system were used to reduce MSA values to take into account human influence. This procedure was used to evaluate land use scenarios for northern Thailand in order to identify major threats to biodiversity and possible conservation hot spots. Originally, a very similar approach based on the concept of hemeroby (Zebisch et al. 2004, chapter four) was considered for the work on the evaluation tool presented in chapter four. It was planned to construct comparative indices between the forest land ecosystems of the remote parts of our research area and the population structures of the land use classes found throughout the research area. This would have resulted in indices very similar to those proposed by Trisurat et al. (2010). After developing these indices for several months, it was chosen not to follow this approach in favor of the one presented in chapter four, mainly because we found ourselves unable to clearly determine which vegetation class to consider as the baseline for comparison of an undisturbed state. The topographic variability of the research area would have favored different “natural” vegetation types, as well as human activities such as agriculture, hunting and gathering. These activities have been practiced over centuries in the area and have most probably already had quite a significant impact on species composition, even in the most remote and now-a-days quite unreachable reserve sites.

Another approach, published by Zebisch et al. in 2004, tested the feasibility of combining measures for the impact of human disturbance with biodiversity assessments based on the analysis of landscape structure and derived indices applied to different land use scenarios. This method uses indices for land use class composition and richness as well as indices for landscape structure derived from the proximity of favorable land use classes. While the assessment of possible landscape matrix effects is very helpful for conservation and biodiversity management planning and helps to identify key factors of possible future developments, its use as proxies for biodiversity is lacking from an ecological point of view. With the methods presented in chapter four it was possible to combine the assessment of species diversity with landscape matrix indices to gain a broader view on the effects of land use change.

One of the major drawbacks of this approach is partly owing to the adaptability and applicability of this tool. As “static” data from field studies was used to assess and quantify the diversity indices developed for this tool, we are not able to predict the dynamic processes that are expected to happen during the transition of single patches of land from one land use class to another. More sophisticated, dynamic modeling solutions would be needed together with a largely expanded background dataset to predict and evaluate e.g. the migration of single species groups, the time-frames for recolonisation of reforested areas or the impact of various levels of fragmentation and isolation on species diversity within one land use class. While the scientific merits of such a detailed modeling process are beyond question, it would move the biodiversity evaluation tool ever further away from its original concept of practicability and relative ease of use.

Even though the modeling process lacks a “dynamic” component, it can be argued that the data serving as the basis of this tool is in fact the result of such dynamic processes taking place in the research area, and is thus representing a snap-shot of the ongoing processes as well as the intermediate status of longer lasting, more drastic changes. The quality of evaluation can thus be improved by long-term monitoring of the research area concerning the long-term effects of land use change on species diversity and subsequent integration of this data into the evaluation tool. The management of these additional datasets as well as additional land use classes such as transitional forests, new agricultural activities or reforestation sites would not prove too difficult due to the straight forward design of the ecological indicators themselves. The time and effort put into such a temporal as well as topical expansion of the tool would however be considerable, as extensive field work over multiple years would be necessary to gather the needed datasets. In research areas where such a data set extending over multiple years and land use classes is already available the expansion of the approach would be a rather time efficient.

The conservation of these valuable tropical forest habitats has been a central part of the storyline developed with the interdisciplinary scenario development approach presented in chapter five. Using the ecological model presented in chapter four it was possible to identify the most valuable land use types for conservation and highlight areas where the coherence of the landscape structure was jeopardized by ongoing land use change. After considering the socio-economic characteristics of this region and the history of land use over the past 25 years, the modeling workgroups of LILAC project were able to develop a storyline for the conservation scenario “Go Green”. Household based economic modeling provided the demands for land considering the preferences of different social groups within the research area as well as an extrapolated market price development of agricultural goods, including rubber. These values were transferred to the land use model CLUE_S that, using an iterative allocation process considering factors such as elevation, available labor or distance to the next road distributed the scenario’s land use demands into the resulting land use map of the “go green” scenario. Trisurat et al. (2010, see chapter five) followed a similar approach by comparing three different storylines using their DYNA-CLUE model, a close “relative” of the CLUE_S model used here. Their storylines were based on linear extrapolation, similar to the example used in chapter four; on policy guidelines derived from government agencies with a given target forest cover, and the last one based on reforestation efforts combined with a decrease in agricultural land use cover. By combining stricter conservation rules with alternative sources of income for the rural population in order to offer an alternative to monoculture rubber farming, the economic models and the land use allocation model predicted a stop in rubber and agriculture related deforestation, and the establishment of a considerable amount of reforested area. This was achieved by introducing an innovative land use type that is closely related to traditional local home garden agroforestry systems. By coupling reforestation efforts with the economic gain derived from intercropping Traditional Chinese Medicinal plants into degraded secondary forests (compare Liu et al. 2006), this scenario was, at least theoretically, able to remove deforestation pressure from the natural forest types and to offer an economic alternative to rubber cultivation. Similar rubber based production systems have been established in Indonesia, with considerable positive effects on the survival of local wildlife (see chapter two, Beukema and Noordwijk 2004, Beukema et al. 2007, Wu et al. 2001).

There are alternatives to following the approach taken with the integration of multi-disciplinary modeling into the iterative allocation processes of CLUE_S. Markov Chain models, on the one hand, usually follow a relatively straight forward approach of predicting future land use distribution based on the trends in past land use change. This approach is similar to the linear extrapolation that was used in chapter four, but the main problem with these approaches is that they do not fully represent the interactions between socio-economic developments, stakeholder preferences and biophysical environments (Trisurat et al. 2010, chapter four). On the other end of the land use modeling scale are multiagent models. These sophisticated software are capable of integrating a wide array of different datasets from multiple scientific backgrounds, but require an intimate knowledge of the software structure itself and of the required datasets. Due to the professional experience present within the LILAC consortium, the modeling group has chosen to develop its own methodology to parameterize the storyline for the land use scenario presented in chapter five.

An alternative approach to scenario design, leading away from the science-driven approaches discussed so far would be an approach often seen when stakeholder involvement seems crucial to the possible realization of a development or conservation project. This wide array of closely related methods most often combines a broadly set up starting phase, where a representative cross-section of the affected communities is being interviewed and information about the projects' aim and procedures is being transferred in public gatherings and community meetings. Based on the participation during this starting phase, key persons within the stakeholder group are being identified and invited to specialist work-groups, where the pros and cons as well as a more detailed view of the impacts of the proposed program is discussed. The main goal of this stage is to form a group of local experts, that have a deeper knowledge of the case discussed, and that are able to transfer this knowledge within their stakeholder communities. After a certain amount of time, usually between four and eight weeks, the expert workgroup is again called together to discuss the topic of the proposed project again, giving the participants and workgroup organizers the possibility to discern if the opinions of the experts have been altered by the intensified involvement into the project. This method is very useful for extension and consultancy, where intense stakeholder participation can greatly improve the acceptability of third-party projects. The biggest obstacle for utilizing this approach is the level and accessibility of information for the stakeholder and especially for the stakeholder-experts group. Especially on further reaching topics such as possible impacts on ecosystem stability on an increased spatial scale as well as possible secondary effects deriving from changes in the socio-economic framework conditions of the stakeholders communities, the possibility to gather additional information from a broader public is important. Rural areas in developing countries often lack information since newspapers are generally scarce, the accessibility of the internet not frequent and television generally not being seen as a reliable source of information, especially when touching controversial social and emotional topics. In order to secure a stakeholder involvement in the approach presented in chapter five, the storyline has been presented to and discussed by workgroups and workshop participants in China and Germany, with representatives from science, public administration and conservation officials taking part.

The downside of this approach is the missing direct involvement of stakeholders. The scenario storylines have never been subjected to the scrutiny of rural decision makers, most of the important aspects and key assumptions for the given storylines have been made by scientific experts from economy, ecology and landscape planning. Whether an innovation would be accepted by local farmers or whether a certain trend in land use change would be deemed probable has been verified during non-representative interviews with a small number of practitioners in the area and via personal communication with experts on regional rural development in Xishuangbanna. An extensive interview campaign would have been necessary to assess the local stakeholders' view of possible future land use scenarios and to gather feedback on the probability and acceptance of the land use scenarios developed within the LILAC project. Although lacking in direct stakeholder involvement, the involvement of local rural communities was indirectly integrated through the partner workgroups in the field of social sciences that contributed valuable information about the farmers' view of the current situation, their willingness to adapt to changes and their personal opinions and views about the future of the research area (Tang et al. 2009).

Communication of such scenarios is another topic that has been addressed within this thesis. Among the scientific community in general, the use of computer-based "3D visualization" techniques is a topic to be treated with care. Many scientists have reservations towards these techniques, with concerns about the quality and the public perception of the visualization leading to skepticism. As has been discussed in chapter six, these visualization techniques are broadly seen as most applicable when communicating to the broader public rather than with colleagues or superior organizations. Here exactly lies one of the main weak points of land use change visualizations. Stakeholders tend to be very observant concerning details that might affect their personal situation, rather than judging a putative regional concept in its totality. By changing single plots of land, that, for the general conception of the proposed project do not have any considerable impact, or by missing out on single details such as certain landmarks (trees, groves, meadows, holy hills) with rather restricted local importance to single individuals, the perception of the concept as a whole can easily be compromised (see Appleton 2003 for more information, chapter six). This is one of the reasons why the visualizations in chapter six are restricted to abstract land use classes being represented by rather uniform vegetation cover, a certain degree of simplification is leading the eye of the beholder away from possible flaws or omissions towards the perception of the fundamental principles intended to be communicated with the visualization.

Concluding, this thesis presented an overview over agronomic, economic and ecological aspects of rubber cultivation and highlighted its implications on biodiversity and nature conservation. The methods found in chapters two, four and five can serve as a guideline for the integration of ecological indicators in land use planning and decision making processes. Although the concepts and topics introduced herein are closely interlinked within the framework of the LILAC research project, the methods and approaches can easily be applied to other areas in the GMS and beyond, be it the expansion of oil palm plantations in the Malayan Archipelago or the fragmentation of forests due to increased population pressure in Central Africa. Nature conservation is facing similar problems all over the developing world, and adaptable approaches like the ones presented here are needed to support decision making processes in order to secure the preservation and long-term survival of the worlds' diversity in species and natural habitats.

Summary

Developing a Biodiversity Evaluation Tool and Scenario Design Methods for the Greater Mekong Subregion

The Xishuangbanna Prefecture in Yunnan Province (PR China) is facing increasing conflicts between rural development and nature conservation because of an ongoing expansion and commercialization of farming. The rapid development of large-scale farming and the improvement of infrastructure throughout the region are posing serious threats to the conservation of endemic species of flora and fauna, while also offering possibilities for enhancing the livelihood of rural populations to an extend never seen before. The expansion of rubber (*Hevea brasiliensis* Willd Ex A. Juss) has caused a reduction and fragmentation of natural and secondary forest cover, thereby decreasing structural and species diversity as well as the loss of valuable ecosystem services. The establishment of intensified agriculture, especially plantations on sloping terrain, often leads to an increased erosion risk, nutrient run-off and sedimentation in water courses. Thus, large scale deforestation is not just a problem for nature conservation but also one for the rural economies. Rural development and simultaneous environment conservation often face trade-offs, especially in regions that host an exceptionally high biodiversity, such as many tropical areas. In order to adequately consider and evaluate these interactions, tools and methods have to be developed that allow decision makers to assess the impacts of different management and infrastructure options on the environment.

The aim of the work presented in this thesis was to analyze and evaluate the effect of large-scale rubber cultivation on local and regional biodiversity by developing methods to integrate field studies from various disciplines into a comprehensive assessment model. This model was then used to highlight key aspects of anthropogenic influence on the plant species composition within the research area and to identify possible impacts of alternative land use decisions. Furthermore, the development of an interdisciplinary approach to scientific scenario design methods has been supplemented with a study on the acceptance of 3D-visualization as communication tool for land use planning in the background of nature conservation sciences.

In order to achieve this, an overview of the agronomical and ecological aspects of rubber cultivation was provided. Literature sources referring to the impact of different cultivation systems on natural biodiversity were discussed and an introduction to the effect of rubber cultivation on Ecosystem Services was given. A method for projection of regionally adapted carbon capture properties of rubber cultivation under suboptimal growth conditions was presented and a comparative assessment of greenhouse gas emissions during the establishment of rubber plantations in regard to the preexisting vegetation was made.

A biodiversity evaluation tool based on the combination of approaches from landscape ecology and empirical data within a Geographic Information System was developed. Detailed data on plant species diversity and distribution were combined with quality criteria like endemism or invasiveness to form spatially explicit biodiversity indices for different land use types in various elevation classes. Up-scaling in accordance to the land use distribution observed allowed the estimation of overall plant diversity and the evaluation of the effect of possible future land use scenarios. Habitat characteristics and spatial distribution were included into the analysis of the land use map derived from remote sensing information to allow for the assessment of fragmentation and landscape matrix structure.

The methodology was tested with an array of possible present and future land use maps. It was possible not only to evaluate the different land use classes within and their distribution throughout the research area, but we were also able to compare distinct sub-regions based on topography or administrative status. The challenges stakeholders and nature conservation face in the different elevation zones of Nabanhe were highlighted and related to the findings of our partner workgroups from economy and social sciences. The feasibility of this approach to administration staff with limited experience in ecological modeling was one of the main goals in designing the methods. Given a reasonable data set on species diversity and distribution within any given tropical research area, this approach will enable planners and nature park administration to quickly project possible consequences on species diversity indices deriving from land use change within their respective research area. Using this approach, the importance of natural tropical forests for the maintenance of species diversity in tropical cultivated landscapes was highlighted.

With the information gained from constructing this evaluation tool, the design and development process for a land use scenario based on the integration of multidisciplinary assessments and iterative scenario refinement with repeated stakeholder inclusion was promoted. By combining stricter conservation rules with alternative sources of income for the rural population in order to offer an alternative to monoculture rubber farming, the economic models and the land use allocation model predicted a stop in rubber and agriculture related deforestation, and the establishment of a considerable amount of reforested area. This was achieved by introducing an innovative land use type that is closely related to traditional local home garden agroforestry systems. By coupling reforestation efforts with the economic gain derived from intercropping Traditional Chinese Medicinal plants into degraded secondary forests, this scenario was, at least theoretically, able to remove deforestation pressure from the natural forest types and to offer an economic alternative to rubber cultivation.

The methods used for this assignment can serve as guideline for future projects that want to implement scenario design procedures based on the combination of social sciences, economics, ecology and landscape planning.

The acceptance and comprehensibility of computer based 3D visualization models for the communication of possible future land use scenarios was also tested. Two alternative scenarios were visualized and compared to the status quo, with questionnaires and guided interviews covering the acceptability and adaptability of such techniques for professionals from various fields of nature conservation.

This thesis presents an overview over agronomic, economic and ecological aspects of rubber cultivation and highlights its implications on biodiversity and nature conservation. The methods discussed here can serve as a guideline for the integration of ecological indicators in land use planning and decision making processes. Although the concepts and topics introduced herein are closely interlinked within the framework of the Living Landscapes China (LILAC) research project, the methods and approaches can easily be applied to other areas in the Greater Mekong Subregion and beyond, be it the expansion of oil palm plantations in the Malayan Archipelago or the fragmentation of forests due to increased population pressure in Central Africa. Nature conservation is facing similar problems all over the developing world, and adaptable approaches such as the ones presented here are needed to support decision making processes in order to secure the preservation and long-term survival of the worlds' diversity in species and natural habitats.

Zusammenfassung

Methodenentwicklung zur Bewertung der biologischen Vielfalt und zur Erstellung von Landnutzungsszenarien für die Greater Mekong Subregion

Die Präfektur Xishuangbanna in der chinesischen Provinz Yunnan sieht sich zunehmend mit Konflikten zwischen ländlicher Entwicklung und Naturschutz konfrontiert. Einer der Hauptgründe hierfür ist die ständige Ausweitung und Kommerzialisierung der Landwirtschaft in der Region. Die Entwicklung großflächiger Landwirtschaft und die Verbesserung der Infrastruktur über die gesamte Region hinweg stellen ernst zu nehmende Herausforderungen für den Schutz endemischer Arten der Fauna und Flora dar, gleichzeitig bieten sie aber auch nie gekannte Möglichkeiten zur Verbesserung des Lebensstandards der Bevölkerung im ländlichen Raum. Die Ausweitung des Kautschukanbaus (*Hevea brasiliensis* Willd Ex A. Juss) hat zu einer Reduktion und Fragmentierung der naturnahen und sekundären Waldbestände geführt, was einen Verlust an struktureller Vielfalt als auch an biologischer Vielfalt ebenso wie an wertvollen Ökosystemdienstleistungen mit sich brachte. Die Etablierung intensiver ackerbaulicher Praktiken führt insbesondere bei der Anlage von Plantagensystemen in topographisch anspruchsvollem Terrain, zu einem erhöhten Risiko von Erosion, Sedimentation und Nährstoffverlusten durch Ausschwemmung in umliegende Gewässersysteme. Dies macht die großflächige Abholzung tropischer Regenwälder zu mehr als nur einem Problem des Naturschutzes, sondern zudem auch zu einem Problem der Agrarwirtschaft und des ländlichen Raums als Ganzem. Um die Vielzahl an Einflussfaktoren berücksichtigen und bewerten zu können müssen passende Methoden und Werkzeuge entwickelt werden, die es Entscheidungsträgern ermöglichen die möglichen Konsequenzen verschiedener ordnungspolitischer Vorgaben, Landnutzungsplanungen und der Entwicklung ländlicher Infrastruktur abzuschätzen.

Die Zielsetzung der hier präsentierten Arbeit war es die Auswirkungen des großflächigen Anbaus von Kautschuk auf die lokale und regionale Artenvielfalt zu analysieren und zu bewerten. Dafür wurden Methoden zur Integration von Feldstudien verschiedener Forschungsrichtungen in ein umfassendes Bewertungsmodell entwickelt. Dieses Modell wurde anschließend genutzt um zentrale Aspekte des menschlichen Einflusses auf die Artenzusammensetzung innerhalb des Untersuchungsgebietes aufzuzeigen und die möglichen Auswirkungen von alternativen Landnutzungsentscheidungen zu ermitteln. Weiterhin wurde die Entwicklung eines interdisziplinären Ansatzes zum Entwurf wissenschaftlicher Landnutzungsszenarien ergänzt durch eine Studie zur Akzeptanz von 3D-Visualisierungen, einem zurzeit im Kontext des Naturschutzes noch nicht allzu vertrauten Werkzeug der Landschaftsplanung.

Um diese Ziele zu erreichen wurde zu allererst eine Übersicht zu den agronomischen und ökologischen Charakteristika des Kautschukanbaus zusammengestellt. Quellen aus der Literatur hinsichtlich des Einflusses von verschiedenen Anbausystemen auf die natürliche Artenvielfalt wurden erörtert und eine Einführung zu den Auswirkungen des Kautschukanbaus auf wichtige Ökosystemdienstleistungen wurde zusammengestellt. Ein Entwurf für die regional adaptierte Prognose des Potentials von *Hevea*-Beständen als Kohlenstoffdioxidsenken unter suboptimalen Wachstumsbedingen wurde erarbeitet und mit einer vergleichenden Analyse zur Etablierung solcher Plantagen unter Berücksichtigung unterschiedlicher Vorgängervegetation ergänzt.

Durch die Kombination von Ansätzen aus der Landschaftökologie mit empirischen Datensätzen aus den Feldarbeitsphasen der Projektpartner unter Zuhilfenahme geographischer Informationssysteme wurde ein Bewertungswerkzeug für biologische Vielfalt entwickelt. Dafür wurden detaillierte Daten zur Artenvielfalt und Verteilung von Pflanzen mit Qualitätskriterien wie Endemismus oder Invasivität kombiniert, um räumlich explizite Biodiversität-Indices für die vorhandenen Landnutzungsklassen zu erhalten. Durch Hochskalierung anhand der im Feld und per Fernerkundung bestimmten Landnutzungsverteilung war es möglich eine Abschätzung zur Pflanzenvielfalt im gesamten Untersuchungsgebiet abzugeben, und die Auswirkungen möglicher zukünftiger Landnutzungs-szenarien zu bewerten. Die räumliche Verteilung und landschaftsökologischen Charakteristika der Landnutzung wurden in diese Analysen eingebunden, um zusätzlich Aspekte wie die Fragmentierung von Waldflächen und die Struktur der Landschaftsmatrix bewerten zu können. Diese Methoden wurden anhand einer Reihe von aktuellen und zukünftigen Landnutzungskarten getestet. Es war damit nicht nur möglich die verschiedenen Landnutzungsklassen und ihre Verteilung im Untersuchungsgebiet zu bewerten, sondern darüber hinaus auch noch klar abgrenzbare Teilregionen zu vergleichen. Die Herausforderungen, denen sowohl lokale Interessengruppen als auch Naturschutz gegenüberstehen konnten somit klar herausgearbeitet und unseren Partnerarbeitsgruppen kommuniziert werden. Eines der Hauptziele bei der Entwicklung dieser Methoden war die Anwendbarkeit durch Verwaltungspersonal mit nur eingeschränkten Erfahrungen auf dem Gebiet der ökologischen Modellierung. Unter der Vorrausetzung eines angemessenen Datensatzes zur Artendiversität und –verteilung kann dieser hier vorgestellte Ansatz es Planern und Naturparkverwaltungen ermöglichen zeitnah die möglichen Konsequenzen des Landnutzungswandelns auf ihre Region abzuschätzen. Desweiteren konnte abermals die Bedeutung des tropischen Regenwaldes für den Schutz der Artenvielfalt in tropischen Kulturlandschaften gezeigt werden.

Mit den Erkenntnissen, die durch die Entwicklung des Bewertungswerkzeugs gewonnen wurden war es möglich den Aufbau- und Entwicklungsprozess eines nachhaltigen Landnutzungsszenarios zu begleiten. Hierfür wurden die Erkenntnisse multidisziplinärer Forschungsarbeit durch schrittweise Anpassungen der „storyline“ nach wiederholter Einbindung verschiedener Interessengruppen kombiniert. Es war möglich durch die Kombination von strikteren Naturschutzvorgaben zusammen mit der Einführung alternativer Einkommensquellen für die ländliche Bevölkerung eine Alternative für die Kautschukplantagenwirtschaft zu entwerfen was dazu führte das die ökonomischen und Landnutzungsmodelle nicht nur eine Stagnation des Waldverlustes, sondern zeitgleich eine Ausweitung der Wiederaufforstungsflächen vorhersagten. Dies wurde erreicht durch die Einführung eines innovativen Landnutzungssystems das stark an lokal vorhandenen „home garden“ Systemen orientiert ist. Durch die Kopplung von Wiederaufforstungsbemühungen mit dem ökonomischen Gewinn aus dem Anbau von Traditionellen Chinesischen Medizinalpflanzen (TCM) in degradierten Sekundärwäldern war es mit diesem Szenario wenigstens theoretisch möglich den Abholzungsdruck auf naturnahe Wälder zu lindern und gleichzeitig eine Alternative zum Kautschukanbau zu liefern.

Die Methoden die für diesen Prozess entwickelt wurden können als Leitlinie zukünftiger Projekte mit der Zielsetzung der Verbindung wissenschaftlicher Ansätze aus Sozialwissenschaften, Ökonomie, Ökologie und Landschaftsplanung für die gemeinschaftliche Entwicklung möglicher Landnutzungs-szenarien dienen.

Weiterhin wurde die Akzeptanz und Verständlichkeit von computerbasierten 3D-Visualisierungen für die Kommunikation von möglichen Landnutzungsszenarien untersucht. Zwei alternative Szenarien sowie der Status quo wurden visualisiert und mit Hilfe von Fragebögen und strukturierten Interviews wurde die Aufnahmebereitschaft durch und Anpassungsfähigkeit für solche Techniken anhand von Experten aus verschiedenen Bereichen des Umweltschutzes untersucht.

Diese Arbeit zeigt eine Übersicht über die agronomischen, ökonomischen und ökologischen Aspekte des Kautschukanbaus auf, und beleuchtet dessen Auswirkungen auf die Artenvielfalt und den Naturschutz. Die hier entwickelten Methoden können Leitlinien für eine Integration von ökologischen Indikatoren in Entscheidungsfindungsprozesse zur Landnutzungsplanung darstellen. Die vorgestellten Ansätze können, obwohl sie angepasst an die Rahmenbedingungen des Living Landscapes China Projektes entwickelt worden sind, problemlos auf andere Regionen angewandt werden. Mögliche Fragestellungen wären die Auswirkungen des sich ausbreitenden Ölpalmenanbaus im Malaiischen Archipel, oder die zunehmende Fragmentierung von Waldflächen aufgrund des Bevölkerungswachstums in Zentral- und Ostafrika. Der Naturschutz sieht sich in der gesamten sich entwickelnden Welt ähnlichen Problemstellungen gegenüber, und anpassungsfähige Ansätze wie die hier vorgestellten werden gebraucht, um Entscheidungsprozesse zur Erhaltung und Sicherung des Überlebens der gefährdeten Arten und vielfältigen Lebensräume dieser Welt zu unterstützen.

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Persönliches

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Berufliche Erfahrung

Seit 07/2007	**Wissenschaftlicher Mitarbeiter** **Institut für Pflanzenproduktion und Agrarökologie der Tropen und Subtropen, Universität Hohenheim** ▪ Promotion im Rahmen des Deutsch-Chinesischen Verbundprojektes Living Landscapes China (LILAC), wiederholte Auslandsaufenthalte in VR China ▪ Ökologische Modellierung und Datenmanagement im LILAC-Teilprojekt „Wandel einer multifunktionalen Kulturlandschaft und seine Auswirkungen auf die strukturelle und biologische Vielfalt“ ▪ Zuständig für die teilprojektübergreifende Koordination von Datenaustausch und Mitglied der projektinternen interdisziplinären Arbeitsgruppe zur Modellierung ▪ Administrator der LILAC-internen Kommunikationsplattform ▪ Zusätzliches Themengebiet: 3D-Visualisierung in der Naturschutzplanung ▪ Projektkoordination des BMZ-geförderten Projekts „Understanding the present distribution of parasitic weeds of the genus Striga and predicting its potential future geographic distribution in the light of climate and land use change” ▪ Betreuung von Masterstudenten ▪ Lehrtätigkeit in den Studiengängen „Agrarwissenschaften (BSc)“, „Nachwachsende Rohstoffe und Bioenergie (NaWaRo, BSc)“ und „Agritropics (MSc)“ ▪ Arbeitsgruppeninterner Administrator (Netzwerk, Hardware, Software) ▪ Verantwortlicher für Organisation, Wartung und Management des institutseigenen Klimalabors
02/2007 – 06/2007	Bewerbungsphase nach Abschluss des Studiums Besuch der Pflichtmodule für den PhD-Studiengang „Agricultural Sciences“ an der Universität Hohenheim

09/2006 – 01/2007 **Wissenschaftliche Hilfskraft**
Institut für Agrartechnik, Universität Hohenheim

- Instandsetzung und Inbetriebnahme einer Anlage für Zugversuche
- Etablierung von Messroutinen für Zugfestigkeitsmessungen an Naturfaser
- Untersuchung der Auswirkungen von Trocknungs- und Alterungsprozessen auf die Faserqualität von *Musa textilis* (Abaca Faserbanane)
- Trocknung und Verarbeitung von *Artemisia spec.*

Studium und Ausbildung

10/2001 – 08/2006 **Universität Hohenheim**
Diplomstudiengang Biologie

- Studienschwerpunkte:
  Physiologie und Biotechnologie der Pflanzen,
  Bestands- und Agrarökolgie
- Diplomarbeit: "Comparison of Abaca growth performance in two multi-strata trials with special reference to fiber yield and surrounding vegetation" (1,3)
- Gesamt-Abschlussnote: sehr gut (1,1)

09/2000 – 06/2001 **Johanniter Unfall Hilfe Esslingen**
Ausbildung zum staatlich geprüften Rettungssanitäter im Rahmen des Zivildienstes, seitdem ehrenamtliches Mitglied sowie mehrmalig im Werksärztlichen Dienst der Daimler AG, Mettingen als Ferienarbeiter tätig.

09/1991 – 07/2000 **Heinrich Heine Gymnasium, Ostfildern**
Abitur mit Leistungskursen Englisch und Chemie

Weiterbildungen

04/2011 – 07/2011	**Hochschuldidaktisches Zentrum, Universität Hohenheim** FIT für die Lehre 1 – Hochschuldidaktische Grundlagen 1+2
10/2009 – 11/2009	**Steinbeis Europazentrum, Karlsruhe** Interkulturelles Forschungsmanagement
09/2008	**3D Nature Academy, Boulder, Colorado** 3D-Visualisierungen: World Construction Set und Visual Nature Studio
09/2007 – 02/2009	**Johanniter Unfall Hilfe Esslingen** Schulung zum Ausbilder im Einsatzbereich Breitenausbildung Erste Hilfe

Zusätzliches

Sprachen	**Englisch**:	fließend in Wort und Schrift
	Spanisch:	gesprächssicher
	Französisch:	gesprächssicher
	Kroatisch:	Grundkenntnisse
EDV	Gute Kenntnisse in MS Excel, MS PowerPoint, MS Word Gute Kenntnisse in ArcGIS und div. Ökologischen Modellen Grundkenntnisse in versch. Programmiersprachen	

Stuttgart, 8. February 2012 Marc Cotter