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Designing a sustainable land use scenario based on a combination of ecological assessments and economic optimization

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ABSTRACT

Land use change and the corresponding effects on ecosystems 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 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 interdisciplinary panels 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 Modelling 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.

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 such as a decrease in structural and bio-diversity as well as the loss of valuable ecosystem services (Wu et al., 2001; Zhu, 2008).

However, one has to notice that rubber cultivation is well accepted among local land owners, as its introduction has

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remarkably improved income and has promoted infrastructural advances and 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 scenario simulations are required, such as the proposed Go Green scenario for testing different options on how to create favourable compromises between ecological and socio-economic interests. These can be reached through incentives based on compensation for abandoning rubber cultivation practices as a kind of 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 to ecologically conducive crops, thereby recognizing the opportunity cost of land. Knowing the value of a land parcel over a year indicates the likely value of necessary compensation payments that might be required for a policy to be successful for that plot. Consequently, we obtain "shadow prices", which are linked to costs and benefits in rubber growth (Hazell and Norton, 1986). These prices reveal payments as costs for governments or societies to increase the ecological "value" of a certain research area and to foster the sustainability of conservation efforts therein. As alternative to rubber in monoculture, a proposed agroforestry system focussing on the sustainable cultivation of Traditional Chinese Medicine (TCM) plants has been developed. Any efforts for cultivation and conservation of TCM would help to provide employment, additional income for farmers and to preserve the natural resources. These activities are aimed at communal secondary forests and demonstrate the potential of "shadow prices" when assessing agricultural land use alternatives.

Our research is based on the assumption that informed land use planning is able to reduce the threats of biodiversity loss while improving livelihoods of local inhabitants and enhancing their socio-economic conditions. To test this hypothesis, we designed a "Go Green" Scenario. This scenario was based on a storyline that describes a more conservation-oriented management of resources in the study area. We followed an approach of integrating disciplinary models in a synthesized approach within one modelling framework. To do so we wanted to find a compromise between the economic value of land and the value of the land for the environment's sake. An interdisciplinary modelling approach was considered necessary to balance the different demands and options for future land use distribution.

2. Materials and methods

When developing plausible scenarios for possible future land use in any given research area, scientists and administrative planners can opt for a multitude of options ranging from artistic interpretation, popular census and strict continuation to 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 research 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 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 km^2 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).

2.1. Scenario assumptions

The main goal was to combine the MAB principles of conservation and sustainable livelihood within the NRWNNR with aspirations of the communities and government aims, without neither proposing economically unrealistic or socially undesired developments nor confining the scenarios to disciplinary navelgazing. Three main assumptions regarding possible environmental improvements had to be parameterized in order to do so. Those were:

(1) A stronger protection of the most ecologically valuable land use types in order to secure the future of conservation efforts within the research 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.

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. 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). 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; Leaman, 2006; Sydara, 2007).

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, education and household income 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.

2.2. Methodology

2.2.1. Biodiversity assessment

2.2.1.1. Plant species diversity. A total of 610 plots were surveyed within the NRWNNR (1252 species from 635 genera and 158 families were identified). To analyze 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 notes of Table 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 and Larsen, 2004). The JackKnife1 method was used to remove sampling bias 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 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