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Land-Use Changes, Mangrove Destruction, and Vulnerability in Maduganga Lagoon, Sri Lanka – Empirical Analyses towards Agent-based Modelling

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Introduction and Objectives of Study

Human use of land is one of the most substantial alterations of the earth system (Vitousek et al., 1997). Global cropland and pastures have increased significantly in the last three centuries, mostly at the expense of forests, natural grassland, steppes, and savannas. Since the 20th century the pace of land-use and land-cover changes (LUCC) has risen even further and is unprecedented in human history (Lambin et al., 2003, Ramankutty et al., 2005). Most scenarios predict a further increase in agricultural land of up to 40% until 2100 (Alcamo and Busch, 2005). LUCC may alter biogeochemical cycles (e.g. through the excessive input of nitrogen), have a direct impact on biodiversity and soil degradation, change water and radiation budgets and contribute to regional climatic changes as well as to global warming (Verburg et al., 2003; Lambin et al., 2001). Environmental degradation may also increase the vulnerability of people to all kinds of biophysical, economic or socio-political perturbations (Lambin et al., 2003; Renaud, 2006).

Because of its complex nature, it is a challenging task to carry out comprehensive analyses and assessments of LUCC. This complexity is mainly caused by numerous driving forces with multiple interactions and feedback loops between the biophysical and socio-economic components of land-use systems (Haggith et al., 2003). These driving forces and their interdependencies operate on different temporal and spatial scales and vary from region to region. An integrated analysis of this complexity is a prerequisite for understanding the multiple reasons and pathways of LUCC and for developing scenarios of future developments in order to support decision-making on the sustainable use of land resources. It calls for multidisciplinary modelling, which combines tools and techniques from natural and socioeconomic sciences in order to highlight interactions between subcomponents of the coupled human-environment system.

Agent-based models (ABMs) have been recognised as an appropriate means for integrated land-use analysis since these tools provide a natural representation of the human-environment systems and are able to represent socioeconomic and biophysical complexity (Parker et al., 2002). Due to their flexibility ABMs can easily be adapted to new situations by adding additional agents or modifying descriptions and aggregations (Le, 2005). ABMs simulate decision-making by individual agents, explicitly addressing inter-agent interactions as well as interactions between agents and their environment. In ABMs applied for simulating LUCC, agents are abstract entities representing land-users, who make relevant land-use related decisions in the respective system. They are autonomous, goal-directed, heterogeneous, and can adapt to new situations (Verburg et al., 2004; Castle and Crooks, 2006). However, informing land management requires realistic ABMs. In order to meet this challenge, behaviour of agents embedded in the system must be calibrated based on empirical data and simulated LUCC should be verified by historical land-use dynamics.

Coastal zones of developing countries are particularly vulnerable areas due to high population density, livelihood dependence on natural resources, and consequently high pressure on these resources. Furthermore people in coastal areas are exposed to several types of natural hazards such as the tsunami in December 2004, which revealed the vulnerability of people living in the coastal zones of many countries, including Sri Lanka which in terms of human toll was the second hardest hit country. One method of protection, which has been discussed in the aftermath of the event, was the establishment of natural barriers such as mangroves along the coasts to reduce the force of tsunami waves. It was therefore decided to select a study site in Sri Lanka (Maduganga Lagoon) that was affected by the tsunami and which also contains some mangrove habitats. Furthermore the competition for natural resources and land in the study area is strong due to high population density and the different types of livelihoods.

The study will analyse the impacts of different policy scenarios on land use around Maduganga Lagoon. Furthermore the collected data are supplemented by additional information in order to conduct a vulnerability assessment to evaluate how the people managed to cope with the impacts of the tsunami and which factors influence their vulnerability to such events and particularly whether or not mangrove strips in the area provided any protection from the tsunami wave. The final objective of applying the agent-based model together with the vulnerability assessment is to explore alternative policy scenarios in order to improve livelihoods and the state of the environment as well as to reduce vulnerability to natural hazards, thereby providing stakeholders with support for making better-informed decisions about land resource management.

Study Region

Maduganga is a brackish water estuary on the southwestern coast of Sri Lanka, approximately 80 km south of Colombo. It is located in the wet zone and receives about 2500 mm of rainfall per year. The water body occupies 915 ha of land, including some 20 islands. It has been declared as a Ramsar Wetland Site in 2003, and it is managed under the Special Area Management Programme by the Sri Lankan government. The main water body is connected to the sea by a canal, whose mouth is regularly blocked by a sand bar. While most parts of the land around the water body are covered by homesteads and small-scale agriculture (cinnamon, paddy, coconuts), there are still some strips of relatively undisturbed mangrove habitats around the water body and along the canal.

The people living in the western part of the lagoon have been severely affected by the tsunami, which penetrated about 1.2 km inland. While in the western and southern part agriculture is only of minor importance for the livelihood of the people, it is dominating in the northern and especially in the eastern part.

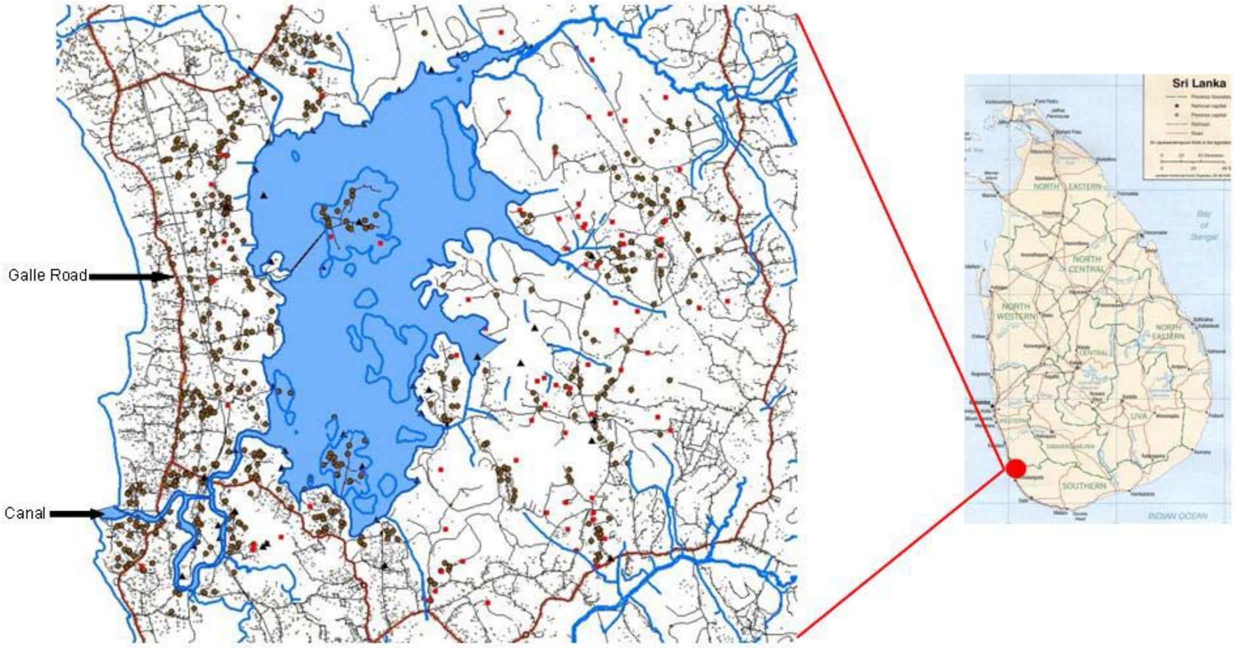

Fig. 1: Location and map of the study area. The brown circles mark locations of interviewed households, the red squares the agricultural plots owned by interviewed households; the red lines mark the main roads around Maduganga.

Materials and Methods

Field data were collected during intensive surveys and empirical analyses in 2006 and 2007 to characterise household behaviour, current land use, as well as historical land-use changes. Interviews with 538 households living around the lagoon were conducted using a structured questionnaire that captured the five asset categories of the Sustainable Livelihoods Framework (i.e. physical, natural, financial, social, and human capital). The concept, which has been vigorously debated in the literature, forms a theoretical basis for deriving indicators/criteria for assessing the performance of natural resource management, and helps to avoid bias selection of indicators from one particular discipline (Campbell et al., 2001).

The questionnaire put a special focus on agricultural practices of the people, income generated from agricultural activities as well as labour input. The homesteads and agricultural plots of all interviewed households were visited to gather spatially explicit land-use practices and outputs. Further information was derived from the collection of relevant metadata such as land-use or management plans from governmental and non-governmental agencies.

Current land use and land cover were mapped using a Landsat ETM+ image from 2003, supported by aerial photographs, topographic maps, and extensive GPS-based field surveys. For the satellite imagery unsupervised classification together with image interpretation from the ground truthing process were used.

Multivariate statistics were used to define and characterise different household livelihood typologies and socio-ecological determinants of their land-use choices. Principal Component Analysis (PCA) has proven to be an appropriate tool for data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of variables, i.e. it is possible to explain the correlation pattern between two or more variables in terms of a few underlying factors, called principal components. Subsequent cluster analysis using the extracted components will identify main livelihood groups.

Vulnerability is a multidimensional phenomenon and therefore requires multidimensional analyses. The household survey, which was based on the five asset categories and linked to the characterized dynamic landscape, provides suitable data for causal analyses in a vulnerability assessment. Statistical analyses can reveal, which factors mainly contribute to the vulnerability of people in the study area. Additionally the questionnaire contained a section on the perception and knowledge about mangroves around the lagoon and another section on damages from the tsunami and subsequent recovering. Qualitative surveys along the canal were also conducted to evaluate any protective effects of the mangroves during the tsunami.

First Results

Through comparisons with aerial photographs from 1956, 1973, 1984, and 1994, the spatio-temporal analysis detected increases in agricultural lands and urban structures during the last 50 years at the expense of mangroves and other forest ecosystems. While the eastern and northern parts of the lagoon are rural areas covered predominantly with cinnamon plantations and scattered homesteads, the southern and particularly the western part along Galle Road have been mainly converted to urban use.

The PCA with the household data revealed that, in addition to household income and total household land, education level, size and labour availability of households are the main variables that differentiate livelihood strategies. As a next step these selected variables will serve as input for the cluster analysis to elaborate the different livelihood groups. Household attributes that correlate highly with the extracted principal components will be used as criteria of automatic household categorization in the agent-based simulation.

Policies as external factors can have a tremendous impact on land-use decisions of households. Thus the most important policies have to be included as part of the modelling process. From the surveys and the analysis of metadata and literature, relevant policy factors selected to study their impacts include: 1) agricultural subsidies (amount and coverage), 2) zoning of protected area around the lagoon (coverage and the degree of enforcement), and 3) changes in fisheries management (number of fishermen, extent of aquaculture) within the lagoon.

In addition, the survey revealed that utilisation of the mangrove strips around the lagoon is rather low, which is probably partly due to the protective status of the mangroves or to incomplete responses to the questions for fear of being accused of misuses of mangrove resources. Few people reported that they saw a protective role of mangroves during the tsunami. The field survey revealed that it is not likely that the mangrove strips provided protection against the forces of the tsunami in that area, either because the extent of the habitats was too small or because the mangroves were too far away from the beach to have an impact on the force of the then weakened energy of the tsunami waves. Nevertheless, the multiple influences of topography do not allow any definite conclusions about the protective effects of mangrove habitats. These results are in accordance with other scientific results, which – after initial reports on anecdotal evidence – later on started to doubt the protective effects of mangroves (Baird, 2006; Kerr et al., 2006).

Next Steps

The surveyed data and extracted parameters/coefficients will be used as input for the agent-based simulation model LUDAS (Land Use Dynamics Simulator), which has been developed at the Center for Development Research (ZEF) and has been first applied to a mountain watershed in Vietnam (Le, 2005). LUDAS consists of four modules, which represent the main components of the coupled human-landscape system: the human module defines specific behavioural patterns of households in the study area in land-use decision-making according to the extracted livelihood groups. The landscape module characterizes individual land patches with multiple attributes representing biophysical dynamics and land-use/cover transitions in response to both household behaviour and natural constraints. The policy module represents public policy factors that are assumed to be important for land-use choices, and finally the decision-making module as the core of the model integrates household, environmental and policy information into land-use decisions.

The proposed agent-based architecture allows integration of diverse human, environmental and policy-related factors into people's decision making with respect to land use and presentation of subsequent accumulated outcomes in terms of spatiotemporally explicit patterns of the natural landscape and population.

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