Linking processes and pattern of land use change

Overmars, K.P.

1 General introduction

1.1 Relevance

The conversion of the earth's land surface by human actions has been extensive in the past and is still on going at a substantial rate (Vitousek *et al*., 1997). Although land use change is not the only component of global environmental change it has major impacts on climate change, ecosystem services, and sustainability (e.g. Moran *et al*., 2004; Rindfuss *et al*., 2004). Land use and land cover changes can induce climate changes directly through changes in albedo and transpiration rates. Land use influences climate indirectly through emissions of greenhouse gases from, for example, vegetation and soils (carbon dioxide) and rice paddies (methane) (e.g. Dale, 1997). Habitat destruction due to land use changes, for example tropical deforestation, forms an important threat to biodiversity (Tilman *et al*., 1994; Turner, 1996; Myers *et al*., 2000). Land use change can trigger soil degradation and soil erosion, which changes watershed properties and may cause flooding at local scales (Chomitz and Kamari, 1998; Bruijnzeel, 2004). Furthermore, unsustainable land use practices can affect soil properties causing loss of agricultural productivity with associated effects for local livelihoods and food security.

Land use change does not affect all regions in the world in a similar way. Some areas experience large changes with a high impact where other areas are hardly affected. One of the countries that is highly affected by land use change are the Philippines. In the past century, this country experienced large-scale deforestation (Kummer, 1992; ESSC, 1999), which was caused by intensive commercial logging and agricultural expansion. A large part of this agricultural expansion occurred in the upland areas (Garrity *et al*., 1993). When cultivating these uplands with arable crops like corn but without soil conservation measures the soils can easily erode (Coxhead and Buenavista, 2001).

The land use changes in the Philippines have major consequences for the landscape and the functions it can provide. The combination of severe loss of natural habitat and high numbers of endemic species makes the Philippines one of the most important conservation hotspots for biodiversity in the world (Myers *et al*., 2000). The Philippines has the highest number (126) of endangered endemic species in the world (Brooks *et al*., 2002). Fifty-three percent (92 species) of Philippine endemic forest bird species is threatened or near-threatened, mainly as a result of deforestation (IUCN, 2005). The catastrophic effects of land slides and flash floods after heavy rainfall, for example in eastern Luzon in December 2004, can mainly be attributed to on-going logging activities in the uplands, which destabilises slopes. Furthermore, many Philippine farmers have adopted unsustainable land use practices, especially cultivation of annual crops in upland areas, which leads to land degradation and restricts future opportunities for sustainable livelihoods (Coxhead and Buenavista, 2001).

These land use changes and their effects also apply to the study area of this dissertation, which is part of the municipality of San Mariano in the northeastern part of the Philippines (Figure 1.1). The area is situated in the transition zone between the lowlands of the Cagayan valley and the uplands of the Sierra Madre mountain range. The area experienced a high rate of deforestation, especially between the 1970s and the early 1990s. This is illustrated in Figure 1.1, which shows the forest cover in the study area in 1972 and 2001. Calculating the deforestation rate based on these maps shows a decrease of dense forest of 600 ha/yr in an area of 48,000 ha. One third of this dense forest changed into cleared area, which includes arable agriculture as well as grasslands, and two-thirds into 'low density forest', including logged-over forest, secondary growth and extensive banana plantations mixed with trees. Part of the study area is situated in the Northern Sierra Madre Natural Park, which is one of the largest contiguous areas of forest left in the Philippines and which is home to many (endangered) species of plants and animals. Although large-scale commercial logging stopped, the area is still a hotspot of change (Verburg and Veldkamp, 2004) due to agricultural expansion, (illegal) logging activities, and on-going immigration of people that search for land to cultivate.

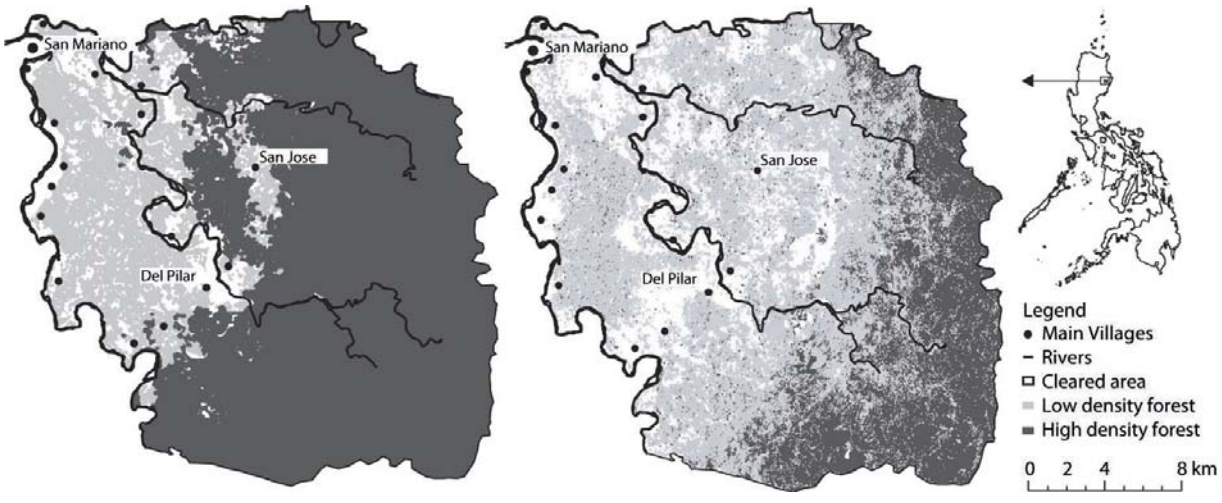

Figure 1.1: Location of the study area in the Philippines (right) and the forest cover in the study area in San Mariano, Isabela, Philippines in 1972 (left) and 2001(center). Interpreted by the authors from aerial photos from the DENR (Department of Environment and Natural Resources) (1972) and satellite imagery (2001).

Since land use change is considered to play an important role in global environmental change it has been given substantial attention in the past and has received even more attention during the last decade. Land use practices influence the global environment and, vice versa, the environment is an important factor in land use decisions. The recognition that land use forms the interface where the human and the natural system interact resulted in a combined project of the IGBP (International Geosphere-Biosphere Program) and IHDP (International Human Dimensions Program on global environmental change) (Turner *et al*., 2004). This so-called LUCC (Land Use/Cover Change) project (Turner *et al*., 1995; Lambin *et al*., 1999) and its successor the Global Land Project (GLP, 2005) aim at integrated social and biophysical research to study the causes and effects of land use change.[1] This dissertation aims to contribute to the methodological questions raised within these projects, as Section 1.3 will detail further.

1.2 Methodological approaches in land use studies

Land change science is by nature a field of science which involves many disciplines including natural, social and geographical information sciences (Rindfuss *et al*., 2004; Turner *et al*., 2004). To study land use, various disciplines have developed their own paradigms and methods. For example, land use studies have been carried out from the perspectives of geography (e.g. Tobler, 1979), economics (e.g. Alonso, 1964), sociology (e.g. Ostrom, 1990), and remote sensing (e.g. Lambin and Ehrlich, 1997). However, these disciplinary approaches can only cover part of the complex system responsible for land use change. It is especially the interaction between the human and the environmental system where land use and land cover change emerges from (e.g. Rindfuss *et al*., 2004; Turner *et al*., 2004). Therefore, in many instances land use scientists have argued that a more integrated, multidisciplinary (or interdisciplinary) methodology is necessary to understand the dynamics of land use change. This view on land use research is the starting point for this dissertation.
Within land use change research three broad categories can be identified (Rindfuss *et al*., 2004): (1) Observation and monitoring of land use change, which involves remote sensing, land use classification systems and quantification of land use changes in the past; (2) Identification of the drivers of land use change and the factors that determine the land use pattern to describe causal processes and (3) Modelling of land use (change) with computer models, which enables combining categories 1 and 2 in a dynamic and integrative manner. Land use change models are important tools in land change science to link information from various sources (Briassoulis, 2000; Verburg *et al*., 2004d). These models can be used to study the processes and dynamics of the land use system and allow researchers to make projections of scenarios of the future. These projections can be visualised to inform policy-makers and to provoke discussion among stakeholders. The work presented mainly covers the fields of driver analysis, process description and dynamic land use modelling (categories 2 and 3).
In this dissertation the concepts of process and pattern of land use change play a central role. Pattern of land use refers to the spatial pattern of land use or land use change over the years, which is represented in maps with a certain resolution and extent. Processes of

[1] *A historical overview of the LUCC project is in Moran et al. (2004) and Lambin et al. (2005) and a summary of the major achievements is in IHDP (2005).*

land use change refer to the underlying drivers and proximate causes that explain land use change (Geist and Lambin, 2002). A description of these processes includes land use (change) and the explanatory factors and their causal interactions (mechanisms) that lead to land use change.
To position the research approaches of this dissertation in the wide range of approaches that are used in land use science two distinctive and contrasting methodologies are identified: 'from pattern to process' and 'from process to pattern'. This classification can serve to broadly describe two basic starting points for studying land use change but is not intended to provide a complete classification of methods in land change science. The pattern-based method can be described as a spatially oriented, GIS (Geographical Information System) based approach. The approach starts out with analysing land use patterns by identifying correlations between these observed patterns and explanatory factors and aims at linking these with the processes that are responsible for those patterns. The process-based approach originates from the social sciences and starts with analysing actors and processes, focussing on actors' decision-making. In this approach the interactions between agents play a central role. The actors' decisions are then translated into mapped patterns of land use and land use change. Broadly speaking, the distinction between pattern-based and process-based research coincides with the distinction between inductive and deductive methodologies. The pattern-based approach induces the driving mechanisms from observed land use data. The process-based approach predicts land use change from causal assumptions and then may test these predictions. Examples of modelling from a pattern-based, inductive perspective are cellular automata (White *et al*., 1997) and neural networks based on land use patterns (Pijanowski *et al*., 2002). Many of the agent-based modelling approaches (Parker *et al*., 2003) fall in the category of process-based, deductive approaches.
To integrate process-based and pattern-based methods Geoghegan *et al*. (1998) suggest to 'socialise the pixel' and 'pixelise the social'. 'Socialising the pixel' refers to making remote sensing images more relevant to the social sciences and aims to push the pattern-based approaches beyond their biophysical dimensions. 'Pixelising the social' aims at making bottom-up, field-based approaches spatially explicit, integrate results with remote sensing information and test the social theory in a spatial explicit way. Roughly then, these two approaches appear as relatively concrete methods congruent with the inductive-deductive dichotomy. However, 'socialising the pixel' and 'pixelising the social' aim at bringing the extremes of the inductive 'from pattern to process' and the deductive 'from process to pattern' closer together in order to come to an integrated approach.

1.3 Objectives

The study in this dissertation was carried out as a project within a larger research program called "Integrating macro-modelling and actor-oriented research in studying the dynamics of land use change in North-East Luzon, Philippines", which was funded by the Foundation for the Advancement of Tropical Research (WOTRO) of the Netherlands Organisation for Scientific Research (NWO). Within this program three projects were carried out. One project aimed at spatially-explicit multi-agent modelling of land use change (Huigen, 2004). This project can be regarded as 'process to pattern' research and starts out from the actors and their decisions, builds rules of actor behaviour in a spatial environment and then arrives at a land use pattern. This project was carried out at the most detailed

level, explicitly identifying separate land use managers and their fields. The second project applies a pattern-based approach at macro-level for the whole of the Philippines. This geographical, GIS-based approach aims at modelling macro-level processes to identify 'hotspots' of change within the country, which can be used to set priorities for research and policy-making (Verburg and Veldkamp, 2004). The project which this dissertation reports on has an intermediate position and aims at linking the micro-level to the macro-level while at the same time combining elements from various disciplines.
The main objective of this dissertation is to develop methodologies to identify important factors of land use and to integrate these factors in order to describe and model the complex land use system, including the mechanisms of change, in a comprehensive manner. To enable the study of the land use system from various perspectives and to facilitate the integration of human and natural sciences both 'pattern to process' and 'process to pattern' research is carried out. Through 'socialising the pixel' and 'pixelising the social', different methods are brought closer together and integrative methods are developed. The interdisciplinary nature of the research questions results in a series of methodological challenges, which are addressed in this study. These include bridging differences in spatial scales (extent, resolution), organisational levels (social, ecological) and temporal scales; identification of appropriate units of analysis that do justice to the research question; comparing and combining different disciplinary paradigms and developing a new approach that unifies the disciplines. Finally, the project aims to integrate all this information in a spatially-explicit modelling approach.

1.4 Outline

At the beginning of this study little information about land use was available for the study area. Land use in the municipality of San Mariano was studied qualitatively to some extent (Van den Top, 1998), but quantitative data, especially spatial explicit data, and analyses about land use change, its causes and effects were not available. The chapters that form this dissertation can therefore be regarded as progressive insight into the land use system and its context in the area.
In Chapter 2 an exploratory analysis is performed to identify the explanatory factors of land use in the area. Two datasets are analysed and compared: a household dataset starting from the people's perspective and a spatial dataset with land as the starting point. In order to make a first effort to 'pixelise the social' and vice versa, the household analysis is carried out first and the results are used to inform the spatial analysis. To make the household approach more spatially explicit and biophysical, the household analysis uses the field level as the unit of analysis to be able to incorporate land related variables like soils and slope. Household factors that show important relations with land use in the household analysis are included in the spatial analysis, besides a set of more traditional biophysical and geographical variables.
Chapter 3 compares the inductive and deductive approaches to model land use decisions. The chapter starts with the identification of six different steps between purely inductive and purely deductive methods and positions various land use studies on this ladder. Subsequently, a deductive and an inductive approach of analysing land use decisions are presented for the household level. The deductive approach makes use of actor-based, process-oriented research framework originating from the social sciences. The inductive

approach uses a statistical approach to derive relations between land use and its explanatory factors. The decision-making theory is applied in a predictive model, tested in a real world case and compared with the results of the inductive approach. This chapter attempts to contribute to the development of interdisciplinary methodology of land use change by combining biophysical and social aspects of land use in one framework.

Chapter 4 deals with integrating different organisational levels and spatial scales by applying a multilevel analysis. This statistical, inductive approach explicitly defines multiple levels within the data and shows what proportion of the variance is explained at which level. The multilevel approach is a statistically sound model for the analysis of data that are hierarchically structured, which is often the case in land use analyses. Explanatory variables can be introduced in the model at their appropriate level, without the necessity to aggregate or disaggregate them before inserting the variables into the model. The construction of the statistical model is informed by the results from Chapters 2 and 3, especially in selecting appropriate variables to be included in the analysis.

In Chapter 5 the information from the analyses of Chapters 2, 3 and 4 is integrated in a dynamic spatial model, which is used to make projections of land use under different scenario conditions. The relations of the deductive model of Chapter 3 are translated to the spatial dataset to create suitability maps that are used in a modelling exercise using the CLUE-S model (Conversion of Land Use and its Effects at Small regional extent, Verburg *et al*., 2002). This approach is compared with a CLUE-S model that incorporates suitability maps derived with a statistical, inductive analysis. This chapter discusses the differences in outcome and the differences in applicability of both modelling approaches in policy analysis.

In Chapter 6 the effects of land use change are assessed for biodiversity. For three land use scenarios land use maps are projected for the year 2015, using the deductive modelling approach of Chapter 5. These land use changes are examined for their effects on endemic bird species richness in the area in a spatially-explicit way by using the relation between landscape characteristics and the occurrence of birds. The scenarios differ in the level of agricultural expansion and forest management. The value of the approach to evaluate policy options for land use and conservation management is discussed.

In the final chapter the experiences and conclusions regarding the interdisciplinary approach of this study are discussed and the main methodological conclusions are summarised and used to formulate recommendations for further research.