4.5 Changes of Land Use

compiled by Frank Ewert, Andrew Hansen and Greg Greenwood

4.5.1 The occurrence and importance of changes of land use and land cover

Land use and land cover change (LUCC) is increasingly recognized as a key component of global change. Land use may influence ecological systems by altering ecological processes and biodiversity, and it may also interact with climate to drive ecosystems.

Managers of Mountain Biosphere Reserves (MBRs) often see LUCC as a more immediate concern compared to climate change. LUCC often correlates with economic development as well as changes in ecosystem services. It can frequently impact other key resources, for instance through impacts on downstream water supply and quality. In addition, and unlike climate change, LUCC appears to be under more immediate policy control. In any event, LUCC, be it regulated or not, establishes a framework that controls the expression of climate change impacts across landscapes. Thus, LUCC is a key issue for many MBR managers and therefore a key entry point for global change scientists.

LUCC is manifest through agriculture, resource extraction, and urbanization, and it is increasing rapidly around many nature reserves in the world (DeFries et al. in press). Many unprotected wild lands around nature reserves have been converted to human uses over the past decades at an accelerating rate. In some developing areas, road construction and demand for resources is leading to the harvesting of primary forest (e.g., Curren et al. 1999). In older settled areas, increases in wealth, technology, and population density are leading to more rural settlement. In the US since 1950, for example, rural residential development was the fastest growing land use type and now covers 25% of the lower 48 states (Brown et al. in review). Rates of land use intensification around reserves may be even faster than on private lands in general. Particularly, nature reserves often contain natural amenities (e.g. scenery, wildlife, outdoor recreation) that attract higher rates of land use activity near park borders (Rasker and Hansen, 2000).

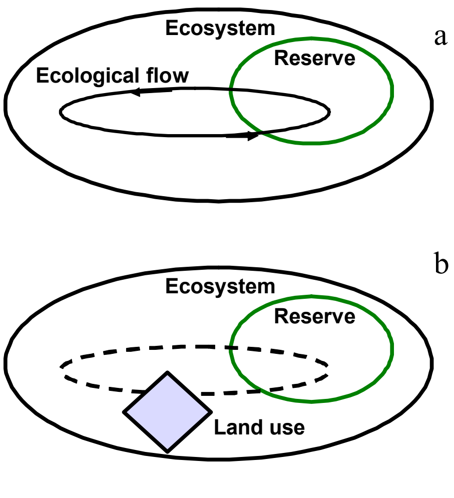

Figure 1. **a)** Nature reserves as part of a larger ecosystem with energy, materials, and/or organisms flowing

through the ecosystem. **b)** Human in the unprotected portion of the ecosystem disrupts ecological flows and alters properties of the nature reserve.

LUCC in and around reserves affects reserve function through ecological linkages (Fig. 1). Reserves are often connected to surrounding areas by flows of energy, materials, and organisms (Hansen and DeFries in prep). The larger, effective ecosystem encompassing a park includes those areas where ecological interactions are strongly tied to park processes. Hence, the functional integrity of ecological processes within parks reflects their inclusion in a larger system. Recognizing parks as parts of larger ecosystems thus facilitates understanding of how land use change in unprotected areas outside parks can disrupt ecological processes within parks. This is especially true for land use, as intense land use change frequently occurs just outside of park boundaries but can exert strong impacts within park boundaries.

4.5.2 Projecting LUCC through models and scenarios

A range of models has been developed to better understand, assess and project changes in land use and land cover (Veldkamp and Lambin, 2001; Parker et al., 2003; Veldkamp and Verburg, 2004). More recently, models have become available that combine knowledge and tools from biophysical and socio-economic sciences (Veldkamp and Verburg, 2004). This has resulted in spatially explicit models focused on patterns of change as well as agent-based models focused on the underlying decision processes (Veldkamp and Verburg, 2004). However, in spite of these advances the mutli-scale analysis of complex systems in a biophysical and socio-economic context remains quite difficult.

Processes of land use and land cover modification, particularly urbanization and the associated agricultural land intensification, require particular attention. Important factors that should be considered when developing future LUCC models are the geographic and socio-economic context of a particular study, the spatial scale and its influence on the modeling approach, temporal issues such as dynamic versus equilibrium models, thresholds and surprises associated with rapid changes, and system feedbacks (Lambin et al., 2000). Factors at multiple scales are frequently important. Factors that explain LUCC in a region arise from both the specific socio-economic and environmental characteristics of that region and processes operating at larger scales. For instance, agricultural land use change within a region cannot be assessed independently of the socio-economic conditions in the country or even larger administrative units (cf. Table 1). The identification and quantification of drivers of LUCC often requires consultation with experts in the specific field and involvement of stakeholders.

Table 1. Key drivers of agricultural land use change in Europe (Ewert et al., 2004a; Rounsevell et al., 2004).

Supply	**Demand**	**Policy**
Land use competition (e.g. urban)	Population (Europe, World)	Market intervention (subsidies, quotas)
Suitable areas	Consumer diet and preferences (meat, organic)	Rural development

Productivity (climate change, CO_2, research and technology)	Import/export regulations (World Trade Organization)	Environment protection (e.g. Nutrient Vulnerable Zones)

The quantification of the factors driving future LUCC is often impossible. In that case, scenarios may be used to explore alternative options of LUCC, considering specific assumptions about changes in environmental and socio-economic conditions. Scenarios are coherent, credible stories about alternative futures. The scenario approach is widely used in many sciences (physical, economic, and social) in varied circumstances and for different purposes (Carter et al., 2001; Alcamo, 2001). Importantly, scenarios are not predictions or preferences of the future. Rather, the main idea of the scenario approach is to use multiple perspectives to explore a specific problem. The development and application of environmental change scenarios has been widely reported (cf. Alcamo et al., 1996; Rotmans et al., 2000; Mearns et al., 2001; Nakícenovíc et al., 2000; Leemans, 1999; Carter et al., 2001).

Early attempts at developing scenarios of socio-economic changes have tended to focus on qualitative descriptions (e.g., Acacia project, Parry 2000; Visions project, Rotmans et al., 2000), short time spans and a 'best-guess' approach (e.g., SeEOR project, Alexandratos, 1995), the global scale (Arnell et al., 2004) or have been constructed for small, well-characterized regions (e.g., RegIS project, Holman et al., 2004) or individual countries (Kaivo-oja et al., 2004). A suitable and widely accepted concept for the development of spatially explicit scenarios for land use change is the IPCC Special Report on Emissions Scenarios (SRES, cf. Nakícenovíc et al., 2000). In the SRES scenarios, principal drivers of land use change (both biophysical and socio-economic) are integrated using an internally consistent framework.

A recent research effort in the context of the EU project "ATEAM" provides an example for the integrated estimation of land use change (Ewert et al., 2004a,b; Rounsevell et al., 2004). The project considered important environmental and socio-economic drivers for Europe and developed scenarios of land use change suitable for ecosystem analysis. The scenarios were based on SRES storylines, from which the key drivers of land use change were identified and scaled down from the global to the regional and sub-regional levels (Rounsevell et al., 2003). Drivers were then quantified to estimate land use changes for the entire study area, which were allocated to individual grid cells across Europe according to scenario-specific rules (cf. Fig. 2). Stakeholders were involved in all activities, including the identification and quantification of drivers and the formulation of allocation rules. To ensure the communication with stakeholders and the subsequent use of the results in regional development discussions, simplicity and transparency were important modeling criteria. This approach might serve as a template for the derivation of LUCC scenarios for MBRs.

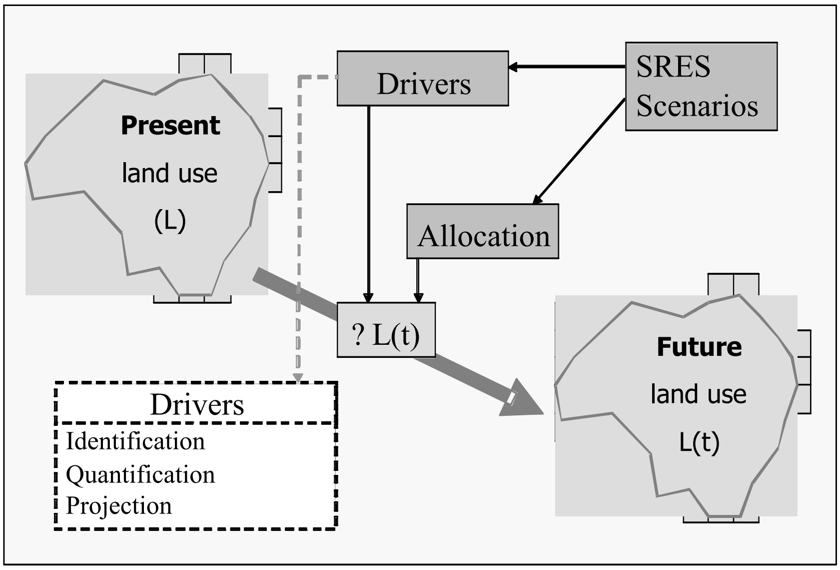

Figure 2. Schematic representation of the general methodology for the development of quantitative, spatially explicit and alternative scenarios of future land use in Europe. The methodology was developed in the EU-funded ATEAM-project (Advanced Terrestrial Ecosystem Analysis and Modeling), (Rounsevell et al., 2003; Ewert et al., 2004a).

4.5.3 Assessing LUCC impacts on reserves

The conceptual model of the relationship between reserves and regions (Figure 1) leads to hypotheses on the ways in which land use outside reserves may influence ecosystem services such as biodiversity within reserves. Hansen and DeFries (in prep.) outlined four general mechanisms through which land use may impact park processes: effective ecosystem size, ecological flows, unique habitats, and edge effects (Tab. 2). *First*, conversion of a park's surrounding landscape reduces the size of its effective ecosystem. Reduction in functional size can simplify trophic structure, degrade the reserve's ability to recover from natural disturbances, and increase species extinction rates. *Second*, land use may inhibit flows of nutrients, energy, and organisms through a park's surrounding ecosystem. *Third*, conversion of surrounding lands may eliminate or isolate unique habitats outside of parks, such as dispersal and migration habitats or important source populations. *Fourth*, edge effects from adjacent land use may introduce invasive species, and alter community structure within parks (e.g., invasive species, predator communities).

Table 2. General mechanisms by which land use surrounding nature reserves may alter ecological processes and biodiversity within reserves. From Hansen and DeFries (in prep.).

Mechanism	Type	Description
Change in effective size of reserve	Minimum Dynamic Area	Temporal stability of seral stages is a function of the area of the reserve relative to the size of natural disturbance.
	Species Area Effect	As natural habitats in surrounding lands are destroyed, the functional size of the reserve is decreased and risk of extinction in the reserve is increased.
	Trophic Structure	Characteristic spatial scales of organisms differ with trophic level such that organisms in higher levels are lost as ecosystems shrink.

Changes in ecological flows into and out of reserve	Initiation and runout zones	Key ecological processes move across landscapes. “Initiation” and “run-out” zones for disturbance may lie outside reserves.
	Location in air- or watershed	Land use in upper watersheds or airsheds may alter flows into reserves lower in the water- or air-shed.
Loss of crucial habitat outside of reserve	Seasonal and migration habitats	Lands outside of reserves may contain unique habitats that are required by organisms within reserves. Organisms require corridors to disperse among reserves or to migrate from reserves to ephemeral habitats.
	Dispersal/ Migration habitats	
	Population source sink habitats	Unique habitats outside of reserves are “population” source areas required to maintain “sink” populations in reserves.
Increased exposure to humans at park edge	Hunting/ Poaching; Exotics/ disease	Negative human influences from the reserve periphery extend some distance into nature reserves.

Management designs thus need to consider not only nature reserves, but also the effective surrounding ecosystem. Considerable attention has focused on regional designs for maintaining connectivity among nature reserves (Miller et al. 2001). However, comprehensive approaches to regional management are only now being developed (Margules and Pressey 2000, Prendergast 1999). The ecological mechanisms presented above provide design criteria for regional landscapes (Table 3). Knowledge of land use, the spatial dynamics of these ecological mechanisms, and the responses of ecological processes and biodiversity provides a context identifying the places in the unprotected parts of the ecosystem that are most critical for maintaining ecosystem function and biodiversity within nature reserves. Several incentive and regulatory tools could be used to maintain ecological function on these keystone locations (Theobald et al. in review). Once management designs are implemented, monitoring can be used to assess management effectiveness, update natural resources objectives, and improve models.

Table 2. Criteria for managing regional landscapes to reduce the impacts of land use change outside of nature reserves on ecological processes and biodiversity within reserves.

Mechanism	**Type**	**Design Criteria**
Change in effective size of reserve	Species Area Effect Minimum Dynamic Area Trophic Structure	Maximize area of functional habitats
Changes in ecological flows into and out of reserve	Disturbance initiation, runout zones Placement in water- or airshed	Identify and maintain ecological process zones
Loss of crucial habitat outside of reserve	Ephemeral habitats Dispersal or migration habitats Population source sink habitats	Maintain key migration and source habitats
Increased exposure to human activity at reserve edge	Poaching Displacement; Exotics/disease	Manage human proximity and edge effects

4.5.4 A LUCC strategy for MBRs

As noted above, the very first step in assessing LUCC impacts on MBRs is an examination of the nature of LUCC surrounding each MBR. While LUCC is clearly important, the exact nature of meaningful change depends on the context of each MBR. In some areas, change from grazing to subsistence cropping is the main manifestation of change, while in others changes in seral stage due to fire are most important. In yet other areas, abandonment of grazing lands and conversion to forests is key while in still others, settlement of those grazing lands is most meaningful. Thus it is not obvious at the outset that a single global classification system of LULC can capture all the meaningful shifts. However, it is reasonable to categorize MBRs and surrounding areas by their biophysical and socio-economic conditions from which key drivers and relationships of LUCC may be derived.

While all the managers present at the workshop desired plausible LUCC scenarios for their MBRs and adjacent areas, only a few of the MBRs appear ready to embark immediately on such modeling or scenario development. Many more find themselves at an early stage of inquiry focused on quantifying the current state of land use and land cover, characterizing the current trajectories of change, and understanding better the underlying processes of change. Clearly, these are important prerequisites for developing scenarios of future LUCC.

The most basic level of a strategy addressing land use-land cover change consists of developing the capacity at MBRs to view and manipulate spatial data and imagery. While some of the MBRs represented at the workshop possessed GIS, several did not. It is hard to imagine that GLOCHAMORE will successfully address most ecological issues, and much less LUCC, without all participating MBRs achieving some minimum competence with GIS as part of their standard operating procedure. Success here involves both equipment and training. Of course, increased GIS capacity is of little use without access to spatial data pertinent to both the current state of land use and land cover, and to its rate of change. This constitutes the second requirement towards LUCC research in MBRs. Fortunately, the most basic data (including digital elevation models and repeated satellite imagery) are available virtually for free, and are being used in many MBRs already. The third component of the basic strategy involves classification and analysis of the data to achieve a comprehensive view of land use-land cover condition and trend. Change detection through comparison of repeated imagery holds particular promise for quickly locating and quantifying the nature of land use-land cover change. Thus, an essential next step for GLOCHAMORE will be to assess the current GIS resources (equipment, personnel and data) at each MBR.

The next level of the strategy involves process studies to understand the origins and causes of the observed changes. This research will require a clear definition of the nature of the expected change (e.g. change in range condition) and the development of specific hypotheses (e.g. changes in production practices of red deer as a function of market prices). It includes the identification of key drivers and relationships determining LUCC. Progress in quantitative understanding of relationships between changes in drivers and LUCC will eventually allow for the most advanced strategy.

This most advanced strategy involves the development of informed future land use scenarios based on spatial data portraying the current conditions and spatial modeling of potential future change considering all important processes determining LUCC. It may be possible to find a shortcut through this work by simply specifying future LUCC scenarios through a stakeholder process (i.e. the land use-land cover equivalent of identifying a warmer and wetter climate change scenario without using GCM or RCM runs) but the power of such scenarios will depend almost entirely on the credence and plausibility accorded them by decision makers and stakeholders. Yet, the combination of simulation modeling and stakeholder involvement has been shown most effectively in developing scenarios of LUCC.

4.6 Remote Sensing of Mountain Environments

compiled by Andreas Kääb

4.6.1 Introduction

Remote sensing technologies provide powerful tools today for observing mountain environments such as Mountain Biosphere Reserves (MBRs). Due to the difficult access to most mountain regions (be it for physical and/or political reasons), remote sensing is often the only way for investigating large sections of the Earth's surface. The purpose of this contribution is to give a brief overview on how remote sensing can contribute to the mapping, monitoring and modeling of mountain environments.

In general, remote sensing methods can be classified according to the platform location (space, air, or ground) and according to the section of the electromagnetic spectrum covered by the sensor (visible and near infrared light, short-wave infrared, thermal infrared, and microwaves). Together with the basic sensor types 'active' (sending and receiving signals) and 'passive' (receiving signals from a natural source), the combination of the above characteristics determines to a large extent the applicability of the data and the cost, expertise and analysis equipment required.

The typical data characteristics for the three platform types are as follows:

- *Spaceborne platforms*: high acquisition frequency of up to some days; coverage of up to ten-thousands of km^2 by one scene; potential coverage of the complete Earth surface; spatial resolution from meters to hundreds of meters; decade-long time series already available; data costs in the order of 1 EUR/km^2 or much less.
- *Airborne platforms*: low acquisition frequency of (usually) years; coverage of a few or a few tens of km^2 by one scene; study areas have to be accessible by plane or helicopter; spatial resolution from centimeters to meters; decade-long time series partially available (mapping authorities); data costs from of a few EUR/km^2 (data reproduction) to hundreds of EUR/km^2 (original acquisition).
- *Terrestrial platforms*: very high acquisition frequency possible (hours and less for automatic systems); coverage of single points or a few hundred meters; study areas have to be directly accessible; spatial resolution from millimeters to meters; data costs from of a few EUR to hundreds of EUR/km^2.

According to the sections of the electromagnetic spectrum exploited, remote sensing data are characterized as follows:

- *Visible light and near infrared (VNIR)*: sensors collect the reflected sunlight (passive sensor); data content similar to what the human eye sees; multi- and hyper-spectral sensors split the