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Analysis of the effects of land use change on protected areas in the Philippines

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Abstract

Deforestation and forest degradation are the most important land use change processes in the Philippines. These processes are an important threat to the highly rated biodiversity of the country. Only a small fraction of the natural forest that once covered the country remains. In spite of different policies that aim to reduce logging recent commercial deforestation, illegal logging and agricultural expansion pose an important threat to the remaining forest areas.

In this paper we discuss the role of (land use) modeling approaches for assessing the threats and trade-offs of protecting the designated nature areas. At the national level different scenarios of land use change and implementation of the protected area policy are evaluated and discussed based on a spatially explicit land use allocation model. For one of the main national parks, the Northern Sierra Madre Nature Park, a detailed analysis is presented based on in-depth knowledge of the region. The two modeling approaches discussed in this paper aim at different scales and provide complementary types of information to support the planning and management of nature conservation strategies. The combination of land use change analysis at different scales respects the hierarchical organization of the land use system and addresses different levels of protected area management. The results indicate that land use change models are useful tools to inform protected area management as long as the selection of the model approach is based on the research and policy questions at the appropriate scale.

Keywords: Protected areas; Asia; Philippines; Land use change; Modeling; Deforestation

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Introduction

Land use and land cover change (LUCC) can be a major threat to biodiversity as result of the destruction of the natural vegetation and the fragmentation or isolation of nature areas. Protected areas are established to limit the extent of land use conversions within delineated areas that are often located in hotspots of biodiversity and assumed to be large enough areas to protect endangered species. However, the simple delineation of park boundaries is most often not sufficient to guarantee the preservation of the ecosystem (Bates & Rudel, 2000). Agricultural expansion on forest frontiers and illegal logging often continue irrespective of park boundaries. A fences-and-fines approach for controlling the park boundaries has proven to be difficult in low-income countries due to the large areas involved, difficult terrains and weak institutions (Barrett, Brandon, Gibson, & Gjertsen, 2001). Policies and management providing incentives to change the activities causing land use conversions are likely to be a more efficient means for park protection. Therefore, a good understanding of the processes causing land use change at the park borders is essential. Such understanding includes both assessments of the anticipated rate and spatial pattern of land use change as well as knowledge of the underlying human and biophysical drivers (Geist & Lambin, 2002; Lambin, Geist, & Lepers, 2003; Turner II, Ross, & Skole, 1993). The methodologies and models developed in the LUCC research community are useful tools for developing such insights and unraveling the underlying processes (Lambin et al., 2003). In this paper we illustrate the role of simulation models of LUCC as a source of information for policy makers and NGOs involved with protected area management. Based on a case study for the country of the Philippines we will discuss the different types of information these models can provide at different scales.

The Philippines is considered to be one of the major biodiversity hotspots in the world (Mittelmeier, Myers, Thomsen, da Fonseca, & Olivieri, 1998; Myers, Mittelmeier, Mittelmeier, da Fonseca, & Kent, 2000), containing one of the highest levels of diversity and endemicity of life forms and some of the most unique habitats in the world. The country's habitats and ecosystems are in constant threat, mainly from unsustainable resource use and development paradigms that tend to increase pressure on scarce resources (Coxhead, Rola, & Kim, 2001). The last remaining representatives of Philippine habitats and ecosystems were set aside for conservation through innovative approaches spelled out in the National Integrated Protected Areas System (NIPAS) Act of 1992, which provides the framework for a decentralized, community-based management strategy.

The NIPAS act lists more than 200 formally protected areas in the Philippines, comprising large natural parks, landscapes and seascapes, wildlife sanctuaries and small watersheds. Of these, however, less than a quarter receive some active form of protection, either through foreign funding or local initiatives (Senga, 2001). Although most forestry, mining and fishing activities are legally barred from the protected areas, the government has been ambivalent in enforcing these laws, in part due to the higher priority given to economic growth (Coxhead, Shively, & Shuai, 2002).

The main trajectory of land use change observed in the Philippines between 1970 and the early 1990s is large-scale logging of the forest areas followed by agriculture. This process was accompanied by road construction for logging and non-logging purposes and by both internal population growth and migration. Logging opened up the forests both by constructing roads into the forests and, at the same time, by removing large amounts of timber, facilitating the clearing of the remaining degraded forests by subsistence migrant farmers (Kummer & Turner II, 1994). This is a process that still continues in spite of the reduced impact of large-scale logging. Small-scale and illegal logging activities still degrade the remaining forests while many local governments upgrade the road system in order to provide better access for the growing number of inhabitants of the frontier zones (Verburg, Overmars, & Witte, 2004). Due to ongoing migration and internal population growth large areas are gradually converted to agricultural land, including the cultivation of cash crops as soon as accessibility conditions allow it (Shively, 2001; van den Top, 1998).

In this context understanding and exploring the spatial extent and underlying processes of land use and land cover change is essential. Such information will help to determine efficient strategies for nature park protection. The next section will discuss how the simulation tools offered by the LUCC community can help to provide such information. This discussion is illustrated by a study for the country of the Philippines in which land use change simulation models are used at both the national and landscape scales aiming at providing information relevant to protected area planning and management.

Models of land use and land cover change

Deforestation within protected areas is frequently monitored by remote sensing techniques to determine the rate and location of deforestation as a means to measure the success of park protection (Arturo Sanchez-Azofeifa, Daily, Pfaff, & Busch, 2003; Pfeffer, Schlelhas, DeGloria, & Gomez, 2005; Sader, Hayes, Hepinstall, Coan, & Soza, 2001; Southworth, Nagendra, Carlson, & Tucker, 2004). These monitoring efforts provide very useful data to evaluate the success of park protection but do not reveal future threats to the park or provide insights into the underlying processes. To provide this type of information, models of LUCC can be used as an additional tool to inform planning and management of parks. In recent years the LUCC community has produced a large set of operational models that can be used to predict or explore possible land use change trajectories (Briassoulis, 2000; Veldkamp & Lambin, 2001; Veldkamp & Verburg, 2004; Verburg & Veldkamp, 2005). A number of reasons for developing models of land use and land cover change can be identified (van der Leeuw, 2004). One advantage of models is that they enable researchers to identify and quantify a wide range of relationships with a degree of precision usually not attained by descriptive approaches. For example, LUCC research requires a systems approach that integrates economic, social, cultural, political, and ecological factors in terms of connectedness, relationships, and context (Gallopin, Funtowicz, O'Connor, & Ravetz, 2001). Models are able to describe the changes occurring in complex sets of relationships, making modeling very suitable to formalize dynamical theories about certain phenomena, which can then be compared with our observations. Dynamical models may also allow the researcher to some extent to experiment with different scenarios to explain particular sequences of cause and effect.

Apart from being a learning tool in unraveling the driving factors and system dynamics, land use change models play an important role in exploring possible future developments in the land use system. With a model the functioning of the system can be explored through 'what–if' scenarios. Based on such simulations alternative land use configurations that result from policy decisions or developments in society can be visualized (Bousquet & Le Page, 2004; Couclelis, 2005). In the context of protected area planning and management the effects of land use change in absence of protection can be evaluated to quantify the pressure of land use change on the area. These exploratory and projective capacities allow models to be used as a communication and learning environment for stakeholders involved in land use decision-making. Projections can be used as an early warning system for the effects of future land use changes and pinpoint areas of greatest conflict between policy aims and projected reality, which are priority areas for in-depth analysis, or policy intervention. In such studies scenarios play a crucial role in dealing with the uncertainty of changes in the socio-economic and political system exogenous to the model (Shearer, 2005; Xiang & Clarke, 2003).

The large diversity in modeling approaches makes it necessary to make a careful selection of the model in advance (Verburg, Schot, Dijst, & Veldkamp, 2004). The variety of disciplines involved in this field of research, but also the diversity of scales, processes and research and policy questions are a reason for the emergence of different modeling approaches. At scales ranging from the regional to the national level only the dominant processes of land use change can be addressed while in local case studies decision-making by individual agents or even the interaction between different agents can be modeled in detail. Case studies have shown that regional variability in human land use relationships may not follow a consistent pattern that can be traced from the global to regional or local scales (Kummer & Turner II, 1994). Other studies have indicated the scale dependence of land use patterns and the associated driving factors (Turner II et al., 1990; Turner, O'Neill, Gardner, & Milne, 1989; Verburg & Chen, 2000; Walsh, Crawford, Crews-Meyer, & Welsh, 2001). No model can address the issues involved with land use change at the different scales synchronously. Different modeling approaches may be required to address the processes at different scales. The level of detail that can be achieved in describing the processes of land use change and the regional variability in these processes is a function of the scale of analysis. At coarse spatial scales it is often possible to describe the overall patterns of land use change without specifying the variability in regional drivers in detail. Often, this variability is obscured by the resolution of the data used. It is not feasible to describe the land use change processes in detail for all regions within a country due to the lack of knowledge of the regional level processes and high data requirements. At the scale of a regional case study it is essential to account for the region-specific processes underlying land use change (Lambin & Geist, 2003). Therefore, in this paper a multi-model approach is used to address the issues at different scales. Such diversification of modeling approaches not only guarantees a good fit with the knowledge and data available at a certain scale, but also ensures that complementary information is obtained.

Study area and methods

Study area

Two modeling approaches are used in this study at respectively the national and landscape scale. The national scale includes the whole of the Philippines at a resolution of 2.5×2.5 km. The landscape scale approach is focused on a small case study area at the border of one of the largest protected areas in the Philippines: The Northern Sierra Madre Natural Park. The Northern Sierra Madre Natural Park is the largest and most important protected area in the country in terms of biodiversity. It is home to 12 habitat types and 40 species of wildlife (most of them endemic) included in the IUCN list of globally threatened species. The study area comprises 20 villages of San Mariano municipality, Isabela province, with a total area of approx. 48,500 ha and is situated between the town of San Mariano in the West and the forested mountains of the Sierra Madre mountain range in

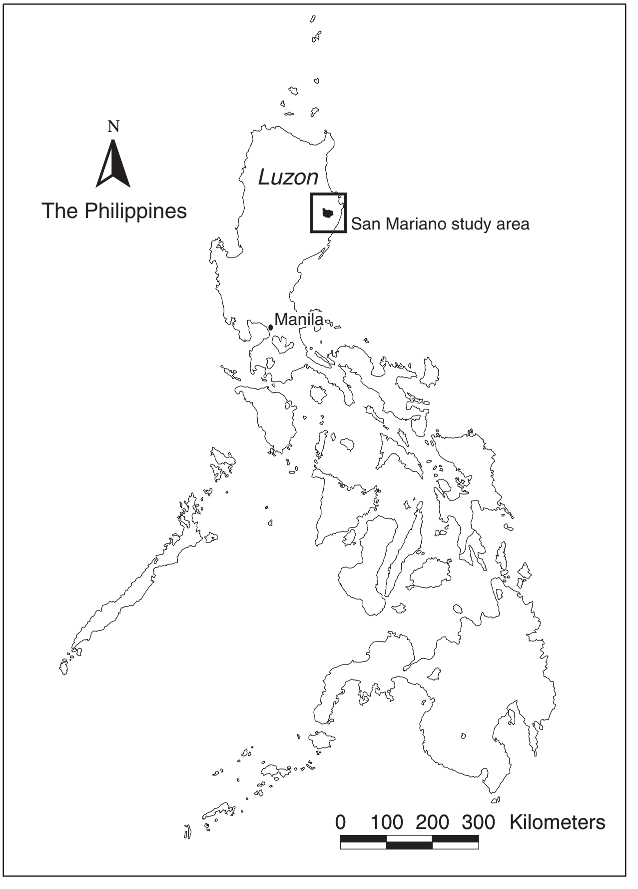

Fig. 1. Map of the Philippines and location of the case study area for the landscape-level analysis.

the East (Fig. 1). The area is inhabited by approx. 20,000 people (excl. San Mariano town) belonging to various ethnic groups. A small portion of the population is indigenous of the area (Kalinga and Aeta) while all others are migrants or descendents of migrants that came to the area from the 1900s onwards. These migrants originate from different provinces of the Northern Philippines belonging, amongst others, to the ethnic groups of Ilocano, Ibanag and Ifugao. Between 1960 and 1990 corporate logging companies deforested a large part of the area. A logging moratorium, issued in 1989 and re-issued in 1992, made people switch from logging-based activities to agriculture. Population is still increasing due to migration and natural growth resulting in increasing threats for the remaining forests due to expansion of agricultural use and logging activities.

Model description

At the national scale a spatial allocation model is used that aims to identify the main deforestation hot spots and threats to protected areas. A more detailed exploration of the spatial dynamics of deforestation is provided within a small region of approximately

20×20 km at the fringe of one of the main protected areas of the Philippines. At this scale a rule-based model is used that is grounded in observed behavior. It analyzes deforestation at the protected area boundary and the degradation of forest patches in the agricultural area at a high spatial resolution.

For each scale the model is specifically developed based on the available information and specific issues relevant to deforestation of the protected areas. Both models are based on the same modeling framework while the configuration of the model is conceptually different and linked to the available knowledge and data at the scale of study. The modeling framework, CLUE-s (Verburg & Veldkamp, 2004; Verburg et al., 2002) is based on the dynamic simulation of spatial patterns of land use change in reaction to pre-defined changes in demand for land by different sectors (e.g., agriculture, wood harvesting). Fig. 2 provides a schematic representation of the functioning of the modeling framework. During each time step the model determines for each location (grid cell) the most preferred land use based on a combination of the suitability of the location itself and the competitive advantage of the different land use types which is a function of the land requirements. If the most preferred land use type requires a land use conversion which is not realistic or not allowed due to spatial policies and restrictions the next most preferred land use type is selected. Spatial policies and restrictions and a matrix listing which conversions are possible need to be specified by the user in advance (see Verburg, Veldkamp, Willemen, Overmars, and Castella (2004) for more information). After allocating the preferred land use to all locations in the study area the aggregate demand for land use types is compared

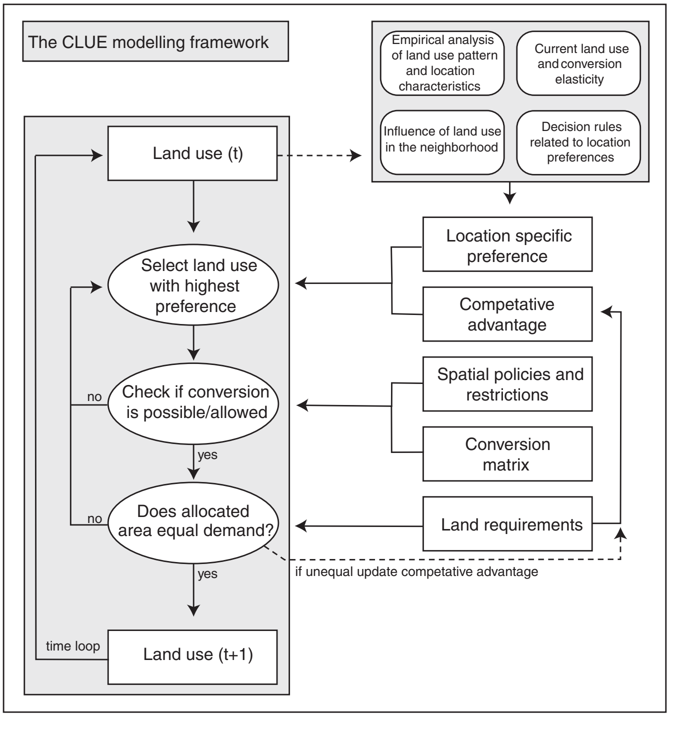

Fig. 2. Schematic representation of the CLUE modeling framework (version: CLUE-s 2.4).

with the allocated areas. If the demand is not correctly allocated the competitive advantage of the different land use types is modified in such a way that the land uses for which the demand was not met obtain a higher preference. Over-represented land uses get a lower preference. The procedure is repeated iteratively until the demand equals the allocated area. The demand for the different land use types needs to be specified by the user in advance. The calculation of the changes in demand is exogenous to the CLUE-s modeling framework and can be based on different techniques ranging from simple trend extrapolation to advanced multi-sectoral models. In the case studies presented in this paper trend extrapolations have been used.

The algorithm of the CLUE-s model is applicable at different scales and capable of simulating different types of land use change trajectories. The actual configuration of the model is dependent on the case study, the dominant land use change processes and the available information and data. Especially the specification of the location specific preference is different for each case study. The location specific preference can be determined by a combination of four different methods (Fig. 2). Empirical/statistical methods are used if information on the (proximate) determinants of land use change is lacking or if the scale of application is much coarser than the scale of our understanding of the land use change processes. The empirical analysis is used to estimate the contribution of different location characteristics, such as soil conditions, accessibility etc., to the suitability of such a location for a specific land use type. The possible determinants are selected based on either theory or knowledge of the study area and the relations are quantified with logit models (Verburg, Ritsema van Eck, de Nijs, Dijst, & Schot, 2004). Upon a change in the value of one of the determinants (e.g., improved accessibility) the new location preferences can be calculated based on these logit models. This specification of location preference does not necessarily lead to causal relations and assumes that the relations based on the current land use pattern remain valid during the simulation period.

When more information is available on the determinants of the location preference in a study area the empirical analysis can be replaced by decision rules that reflect our knowledge of the processes. These decision rules should specify for each location the relative preference of the different land use types. Often it is assumed that neighboring land uses have an influence on each other leading to spatial autocorrelation in land use patterns (Anselin, 2002; Munroe, Southworth, & Tucker, 2002). This can be a result of either the land tenure structure or through processes like agglomeration effects in residential land use. These types of processes can be captured by using the composition of the neighborhood as a determinant of the location preference. The relation between the location preference and the neighborhood composition can be determined either by decision rules, as in most cellular automata models, or based on statistical analysis (Verburg, de Nijs, Ritsema van Eck, Visser, & de Jong, 2004). At each time step of the analysis the location preferences need to be updated to account for changes in neighboring land use.

Finally, current land use is in many cases an important determinant of the location preference. Land conversions are often costly, e.g., after establishing a plantation of fruit trees the owner will not consider to 'move' his plantation to a nearby location due to the high costs involved in establishing a plantation. Other conversions are almost irreversible, e.g., residential area is not likely to be converted back into agricultural area. Therefore, for each land use type a conversion elasticity is assigned that increases the location specific preference for locations where this land use type is found in the current situation. During the simulation these preferences are updated to account for the simulated changes in land use.

The final location specific preference used in the simulations is determined by a mix of these four components based on the preferences of the model user and the available knowledge and data. This mix can be different for each land use type and each application. This makes the modeling framework very flexible and enables configurations that classify the model as either a (constrained) cellular automata model, an empirical–statistical model or a dynamic simulation model (Lambin, Rounsevell, & Geist, 2000).

For the models used in this paper two very different configurations were chosen for the national- and landscape-level case studies. In the model application for the Philippines as a whole the location preference is determined by a logistic regression approach based on current land use patterns combined with land use type-specific conversion elasticities. The factors included as determinants of the location preference are market accessibility, altitude, road access, population density and slope. More details on the model configuration can be found in Verburg and Veldkamp (2004). At the national level it is not possible to capture the land use change processes itself in a simulation model due to the large variety in underlying processes, the level of aggregation and the lack of data. At the landscape level these restrictions no longer hold and it is possible to construct land use change models that represent the land use change processes in more detail including the specific conditions of the case study. Furthermore, the smaller spatial extent allows a higher spatial and thematic resolution that better links the land units to the units of decision-making: the individual households. The landscape-level model is based on a land cover interpretation of remote sensing images (SPOT images for 4-21-2001 and 7-21-2002) and extensive field work in the area between 2001 and 2004 in close collaboration with local institutes (Isabella State University). For the model-based analysis a spatial resolution of 50×50 m was chosen since this spatial resolution corresponds best with the size of the fields managed by farmers in this area (based on information obtained in a farm survey). The model is therefore specified with household-level decision rules regarding the management of fields. Both the conversion rules and the location preferences were based on socio-economic field research at the household and pixel level by a combination of quantitative and narrative research techniques including 155 structured interviews (Overmars & Verburg, 2005; Overmars, Huigen, & Groot, 2006). The specification of the rule set follows an actor-based framework ('Action-in-Context') designed by De Groot (1992), based on concepts of Vayda (1983). The rules describe the perceived suitability of the locations within the study area for different land use types. In addition, 'implementable options' that describe the possibilities farmers have for land use conversions are specified by defining which conversions are possible at the different locations (Overmars, Huigen et al., 2006). The actual calculation of changes in land use is made at yearly intervals (Overmars, Verburg, & Veldkamp, 2006). The approach includes factors such as the variety in ethnicity among villages and the perception of risk as a factor determining land use decisions. Such factors could not be included in the national-level model because these conditions are specific to the region. More details on the model configuration can be found in Overmars, Verburg et al. (2006).

Results

Macro-scale spatial land use change model for the Philippines

In order to analyze the pressure of land use change on the protected areas of the Philippines, simulations for a period of approximately 20 years were made at a resolution of 2.5×2.5 km. The most recent detailed land use maps available for the Philippines are valid for 1990. Therefore, the analysis was made for the period 1990–2010. Scenarios were used to deal with uncertainty in the implementation of spatial policies.

The potential pressure of land use change on parks was determined by generating the spatial pattern of land use change given a pre-determined continuation of the aggregate trend in deforestation. Four different scenarios were used to account for different spatial policies. Scenarios 1a and 1b assume no enforcement of the protected areas. In Scenario 1a no spatial policies with respect to the allocation of agricultural expansion have been defined, while in Scenario 1b it is assumed that conversion to arable land, plantations or mixed cropping is only allowed in areas that are classified as suitable for these land cover types. These areas are delineated by the 'Network of Protected Areas for Agricultural and Agro-industrial Development (NPAAAD)' identified by the Department of Agriculture to ensure the efficient utilization of land for agriculture and agro-industrial development and promote sustainable growth. We have assumed that the conversion to grassland or extensive cropping does not follow these spatial policies. Scenarios 2a and 2b are based on the same overall rates of deforestation and agricultural expansion as in Scenarios 1a and 1b. However, in these scenarios we have assumed a strict protection of the main protected areas. Main protected areas are defined by IUCN categories II and III and have, in the Philippines, the status of Natural Park or National Park under the NIPAS system. All other nature reserves or heritage sites are assumed not protected. Scenario 2a does not include spatial policies for agricultural expansion while in Scenario 2b the same policies as in Scenario 1b are assumed.

Fig. 3 presents the results for Scenario 1a. Deforestation is found along the frontiers of all main remaining forest areas and hot spots are found on Mindanao, Samar, Palawan and along the entire frontier of the Sierra Madre mountain range of Luzon. In some locations these hot spots of deforestation overlap with the protected areas. For each of the important protected areas (IUCN categories II and III) the deforestation was calculated as a fraction of the total park area (Fig. 3d). Hence on the basis of the overall assumptions and assuming no enforcement of forest protection, the protected areas are expected to face a strong decrease in forest cover. Especially the protected areas on the island of Luzon are heavily threatened by deforestation. The Northern Sierra Madre National Park, that still contains a large area of primary rainforest, is expected to be under high pressure from deforestation. Some other national parks are under less pressure, in a number of cases because they are limited to the upper slopes of steep mountains that are inaccessible for agriculture.

The results of all scenarios are summarized in Fig. 4. The overall rate of deforestation as imposed on the model is equal in all scenarios. However, the spatial allocation is widely different. The deforestation is assessed for the important parks that are assumed to be protected in Scenarios 2a and 2b and for all parks that have some type of official status ranging from protected landscapes to heritage sites. The different spatial policies for agriculture do not cause a very different impact on the protected areas as a whole, although the spatial pattern of threats is somewhat different. The protection of the important protected areas results in only a slightly lower impact on all parks together. Clearly under the model assumptions, the protection of the important parks will cause a larger deforestation in the other parks as a tradeoff when these are not protected. All results indicate that many parks are under severe pressure for deforestation if there is no change in demand for agricultural land and timber. Alternatively, the pressure might be reduced somewhat if the productivity of existing agricultural areas increases significantly.

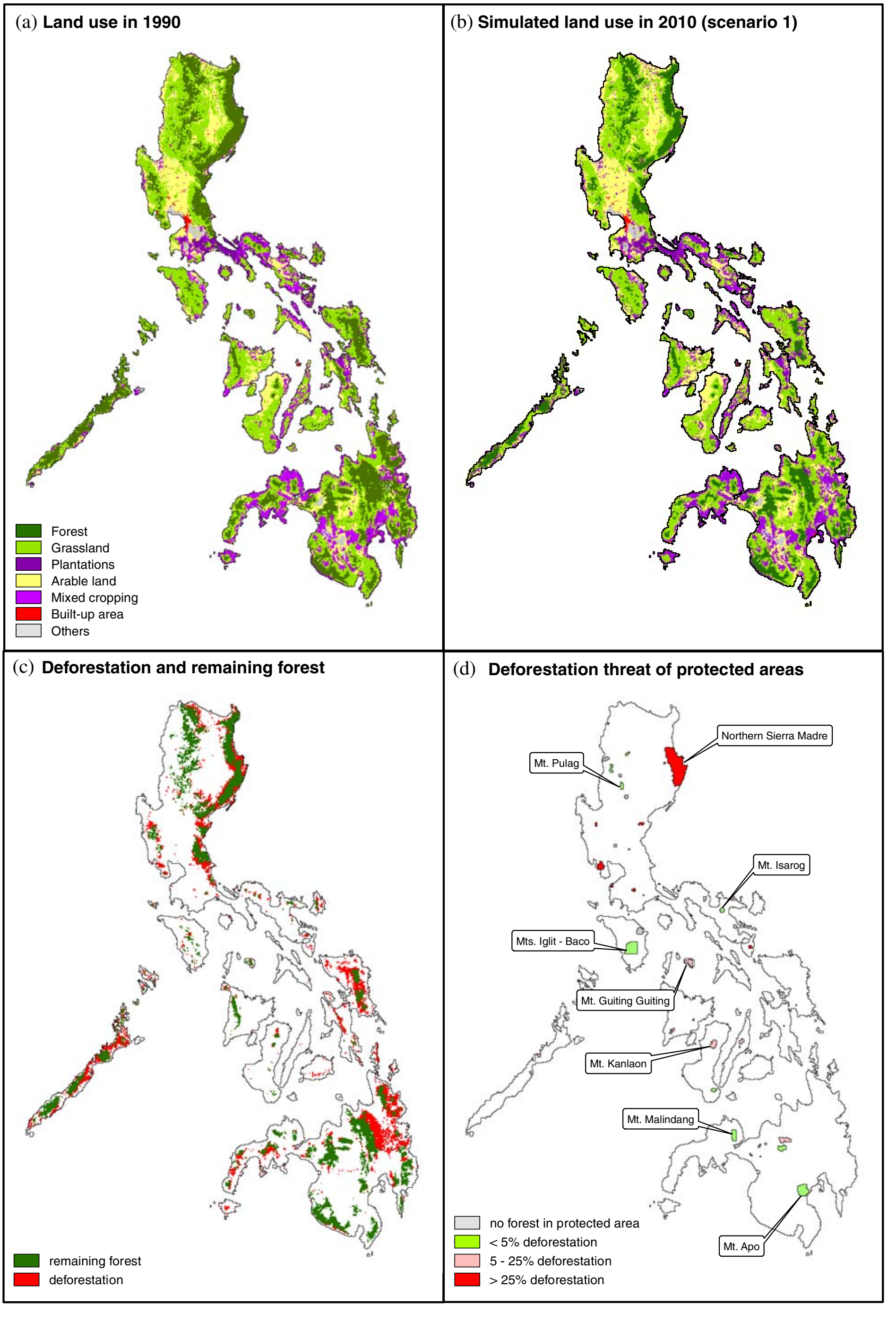

Fig. 3. Observed and simulated land use for Scenario 1 (a and b) and indication of overall deforestation (c) and deforestation threat for the main protected areas (d).

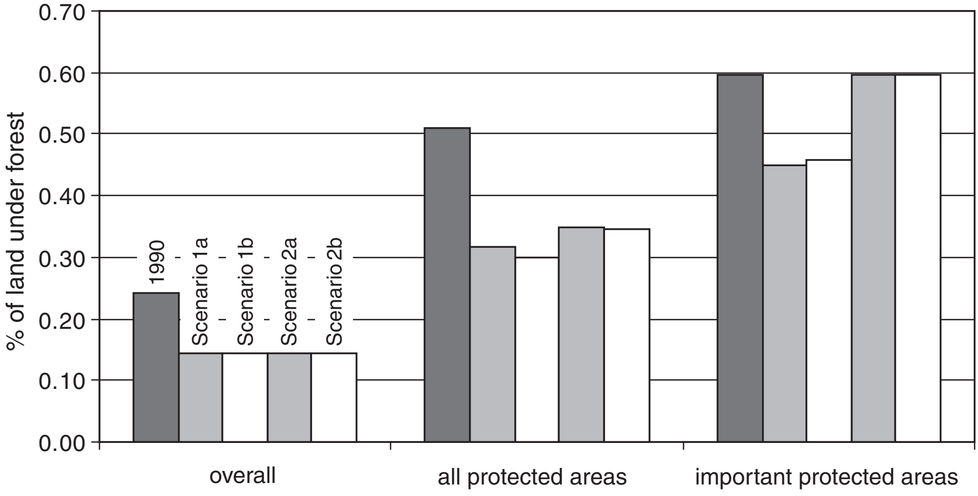

Fig. 4. Percentage of land under forest in the different scenarios for the Philippines as a whole, all protected areas and the most important protected areas (IUCN classes II and III).

Landscape-level models of land use change patterns

A landscape-level analysis of land use changes is made for an area at the border of the Northern Sierra Madre National park. This area was identified in the national case study as a major hot spot of deforestation.

Fig. 5 presents the observed land use changes over the past 30 years based on aerial photographs and remote sensing and the predicted land use changes with this model for the next 20 years for one scenario of future development. In this scenario the rate of deforestation is expected to reduce to approximately one third of the rate over the past 30 years due to the ban on corporate logging. Already in the current situation deforestation has reached the park boundaries and the buffer zone has experienced serious deforestation. Besides the conversion of forest to agricultural area, illegal logging causes the deterioration of forest cover at the forest frontier, at easily accessible places within the park and in remaining forest patches within the agricultural area. The simulation shows that if the assumed trend in demand for agricultural land continues, forest cover within the park area is seriously threatened within the next 20 years. Although policies may forbid such intrusion into the protected area, pressure on the land is very high due to high population growth, small land holdings per farmer and limited possibilities to further intensify agricultural practices (van den Top, 1998).

The results indicate that remaining patches of (secondary) forest and grassland within the agricultural area may be reclaimed if they are suitable for agriculture. The loss of forest patches in the agricultural area is a common phenomenon in the region. In most areas that are further away from the forest frontier hardly any forest patches remain. The simulation results indicate that also in this area the forest patches will diminish in time. This has negative effects on the biodiversity of the agricultural landscape, since these patches are home to many birds, bats and other species (van Weerd, Strijk, & Snelder, 2004).

Fig. 5. Generalized land use in San Mariano municipality: 1972 and 2002 based on interpretation of respectively aerial photographs and SPOT images; 2022 simulated by the spatial landscape-level model.

Although the historic and simulation data reveal a typical deforestation frontier similar to the results of the macro-level model, the dynamics at this frontier can be studied in more detail and scenarios of the expansion of different crops can be considered. Insight in the crops that are cultivated at formerly forested locations is important since the expansion of different crops leads to different patterns of deforestation. Fig. 6 shows a detailed classification of the simulation results in which the dynamics of the different crops can be studied. Rice fields are mainly found in the valleys surrounding the villages as this is a subsistence crop that requires intensive management. Extensive cultivation of banana (*Musa* spp.) is found throughout the whole area on steep slopes and is also found near the forest frontier. Cultivation of banana is often used as a means to obtain de facto land tenure and can take place at considerable distance from the residence of the farmer. Such lands are also used for land speculation. The visualization of the spatial consequences of this process shows that policies that reduce land speculation may be successful in reducing the impact on protected areas. Other dynamics at the forest frontier include the deterioration of the forest cover through logging and some conversions between grassland and open forest due to regrowth and fires.

With this model it is also possible to analyze the potential impact of upgrading and expansion of the road network as planned by the local government. Through such scenario analysis the consequences of infrastructure planning on the spatial patterns of land use can be assessed. Different model runs have indicated that in this region the main threats to the park are found in the high population growth (both natural growth and migration) resulting in a high demand for agricultural land and the upgrading of the road network near the park boundary that will provide better access to that area.

Discussion

Each of the two land use modeling approaches can provide information to policy makers, NGOs or park managers useful to target and improve planning and management of protected areas. At the same time, large differences in the information that can be provided are apparent. At both scales specific issues were addressed and a different spatial and thematic representation of land use was used. The differences in modeling technique and land use representation also pose specific issues for the interpretation of the results.

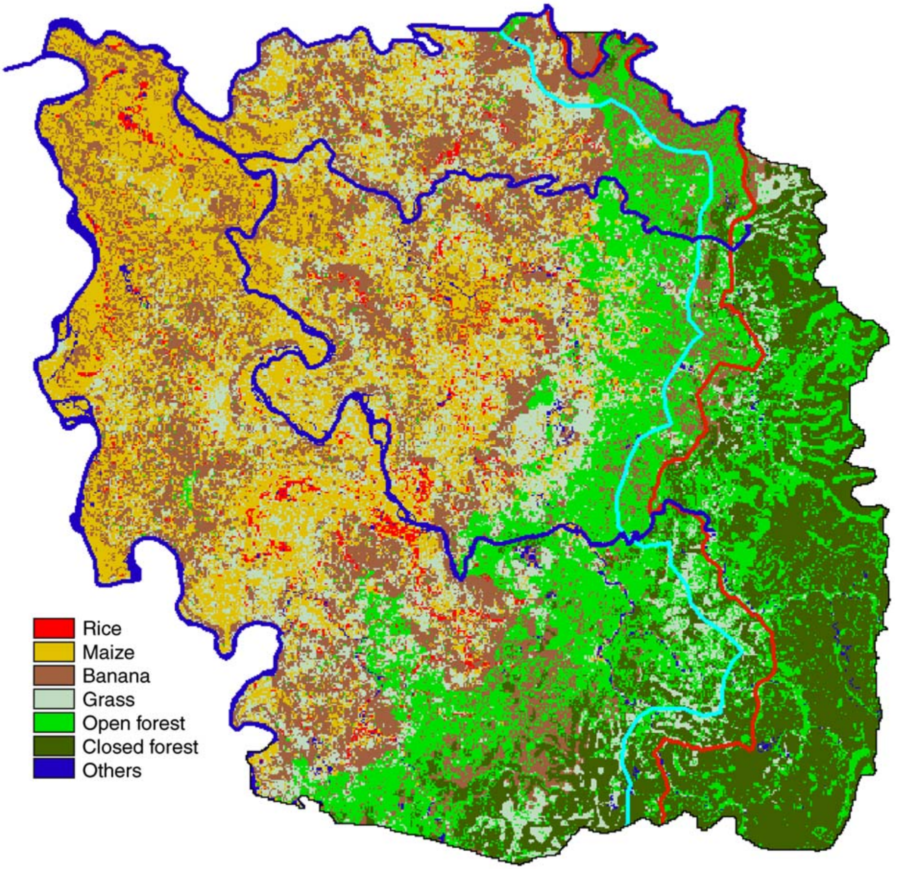

Fig. 6. Simulated land use distribution in San Mariano municipality for 2022.

National-level model

In the national-level model, the relations between the supposed (proximate) driving factors and land use are quantified by regression techniques based on an analysis of current land use patterns. Such analysis does not capture the mechanisms of different processes underlying land use changes and therefore does not guarantee causality of the relations. However, at relatively coarse resolutions the relations between driving factors and land use are the result of the aggregate impact of different actors and different processes that act below the resolution of analysis. It is not possible to quantify these aggregate processes by analytic or narrative techniques due to the complexity of aggregation and upscaling (Verburg & Chen, 2000; Walsh, Evans, Welsh, Entwisle, & Rindfuss, 1999). Therefore, regression techniques are useful at this scale to describe the dominant associations between (proximate) driving factors and land use. This method is commonly used in land use modeling efforts (Müller & Zeller, 2002; Munroe et al., 2002; Nelson & Hellerstein, 1997). Projective use of the empirically derived relations is restricted to scenarios in which no major changes in the processes of land use change are assumed.

The results indicate which areas are expected to face most pressure from deforestation. As illustrated in Fig. 3d this type of information can be used to determine the threat for existing protected areas and other areas that may need to be protected if the forest is to be maintained. Nature conservation strategies are often based on a combination of the valuation of the remaining resources, the threat to these resources and the costs of preserving (Ando, Camm, Polasky, & Solow, 1998). Scenario analysis at the national level can provide information needed to inform the formulation of such conservation strategies. A similar modeling approach is proposed by Pfaff and Sanchez-Azofeifa (2004) who created an index of deforestation pressure based on an econometric model to inform park planning in Costa Rica. As is illustrated in Fig. 4, such modeling studies can identify the trade-offs of protecting a number of areas for the remaining forest resources and provide information to fuel the discussion on the effects of natural park protection. It is well acknowledged that park protection cannot be regarded in isolation and evaluations of its effectiveness should also include the impacts on the surrounding areas in order to establish well-balanced strategies for conservation (Bishop, Phillips, & Warren, 1995).

The high level of spatial and thematic aggregation of the model configuration at this scale has some implications for the interpretation of the results. The results mainly identify frontier deforestation. This is of great value because conservation of frontier forest is of major importance from a biodiversity point of view. Second, there is evidence that once forests are fragmented, they disappear more rapidly in incremental processes that are harder to stop (Etter, McAlpine, Pullar, & Possingham, 2005; Mertens & Lambin, 1997). The process of frontier deforestation has to be distinguished, however, from the clearing of forest remnants in existing agricultural or peri-urban areas. The Philippines has, as many countries with abundant forest margins, large areas of mosaic landscapes in which forest patches of different size remain. Large changes may occur in these areas where most primary forest has already been cleared and reduce their remaining value for biodiversity conservation. Such processes cannot be identified in the results of the national scale modeling exercise since these mosaic landscapes cannot be represented correctly at this scale. In the interpretation of results one should account for this rather than assuming that nothing happens besides the identified 'hot spots' in the model results.

Landscape-level model

This modeling approach differs on two aspects with the national-level model described above. The high spatial resolution allows investigating the changes in landscape pattern in more detail than the macro-level approach. The changes in the landscape mosaic of the agricultural area are also shown in great detail. Degradation of forest patches can be distinguished and the effects on biodiversity and landscape diversity can be assessed (Pimentel et al., 1992). The second main difference with the macro-level approach lies in the specification of the land use decision-making in the model. Instead of specifying the land preferences based on empirical associations between current land use and (proximate) driving factors, the model is specified based on extensive knowledge of the region, questionnaires and empirical analysis of spatial data. So, instead of determining the process from the empirical analysis of the pattern, this model uses a process-based analysis to project land use patterns. These are very different modeling concepts (Laney, 2004) that relate to a fundamental difference in scientific approach, but are also dictated by scale and available data and resources. A process-based approach is feasible when the spatial resolution of the analysis corresponds to the level of detail (or social organization) at which the processes are described. Application of a process-based approach at the macro-level would fail since the spatial units represent aggregate decision-making that cannot be obtained from field surveys on individual fields and actors.

A remaining simplification in the description of the decision-making processes in this landscape-level model is the assumed homogeneity of decision-making throughout the region. The same suitability and conversion rules are assumed to apply to all spatial units (pixels) within the study area. Furthermore, decision-making is simplified by translating behavior into preferences for cultivating crops at certain locations and the specification of conversion rules based on the available (implementable) options open to farmers. The approach does not account for the structure in land organization which is mainly driven by land ownership patterns and characteristic management units (Overmars & Verburg, 2006). Specific ownership situations can cause the land use patterns to deviate from the simulated pattern, e.g., a number of forest patches that are projected to be reclaimed for agriculture may in reality not be reclaimed if owned by somebody with other monetary or land resources than most farmers or by an urbanite who may cherish ownership of a patch natural forest more than of just another patch of maize land.

Other modeling approaches

Although the modeling approaches in this paper represent a large group of land use change models it should be noticed that other model types are available that could provide useful information with respect to park management as well. For instance, the models presented in this paper aim at describing and exploring possible developments of the land use system for different development pathways. Another group of models, prescriptive models, aims at the identification of optimized land use patterns given a set of objectives and constraints (Gilliams, Raymaekers, Muys, & Orshoven, 2005; Roetter et al., 2005). Such results cannot be obtained with the models used in this study.

In both models used in this analysis the unit of analysis is an area of land, i.e., a pixel. Land use changes are calculated for these spatial objects, directly resulting in maps that show the changes in land use pattern. A disadvantage of this 'land-based' approach is the poor match with the agents of land use change (Rindfuss, Walsh, Mishra, Fox, & Dolcemascolo, 2002; Rindfuss, Walsh, Turner II, Fox, & Mishra, 2004). Individual farmers or plot owners are not represented explicitly and the simulations do not directly address the units of decision-making. Another type of model uses individual agents as units of simulation (Bousquet & Le Page, 2004; Parker, Manson, Janssen, Hoffman, & Deadman, 2003). Such multi-agent models emphasize the decision-making process of the agents and the social organization and landscape in which these individuals are embedded. A main drawback of multi-agent modeling is the high number of variables in the models and with that, the depth of field-level knowledge needed to specify the model with any degree of empirical confidence. Therefore, multi-agent models develop their strength only when an in-depth analysis of the social dynamics underlying land use decisions is needed and useful to better inform the management of the protected area and surroundings. Huigen (2004) provides an example of the use of multi-agent modeling for the San Mariano area. In his study a multi-agent model is used to test hypotheses of the processes underlying the demographic dynamics in the area and the settlement patterns of the different ethnic groups. Migration and natural population growth have been identified as important determinants of the threat to the nature park guiding both the demand for agricultural land as well as the occupation pattern. However, the spatial model presented in this paper cannot address these demographic patterns since these are very much linked to the population dynamics, family structure and interactions between ethnic groups and, moreover, linked to the (absence of) population control and migration policies. Huigen (2004) indicates based on the results of his multi-agent model that besides migration and internal population growth the ethnic origin of the population has an important influence on the spatial distribution of the population in the study area. Such understanding of the population dynamics is important to nature conservation policies in the area since the different ethnic groups in the region clearly have different land use strategies due to different crop preferences and use of technologies. Such differences in land use strategies can be explained by the cultural tradition and the crops suitable to the region of origin. Fig. 7 provides an example of the simulation results by showing the land occupation by the different ethnic groups (Huigen, 2004). Park protection would certainly be enhanced if population growth and settlement patterns would be regulated and new settlements in the buffer zone of the park would be avoided. However, the tradeoffs for the rural livelihoods in the region are likely to be numerous. In order to implement sound and sustainable measures a good understanding of the social processes and spatial structure of the settlements is needed. The multi-agent framework by Huigen (2004) may provide a formalized structure for analyzing such dynamics. Furthermore, the response to alternative measures to reduce the impact of people on the park can be explored. As such, multi-agent models may provide a very different type of information complementary to the results of the models presented in this paper.

Policy implications

In this paper we have focused on the potential role of land use models in informing park planning and management. The main contribution of the modeling approaches is in the visualization of the ongoing land use changes and the structured analysis of the proximate processes leading to these changes. Such insights are important to scientists, policy makers and park managers alike: without a deeper understanding of the critical processes determining 'people and park' interactions most measures aimed at protection have high probabilities of failure. It should be noted that the presented models do not provide solutions for the natural resource management issues in the Philippines. Presenting clear-cut solutions for land use decisions to policy makers often disregards the different opinions among stakeholders and the policy making context. Projects that used land use models as a tool to provoke and inform discussions among different stakeholders and policy makers have the potential to be more successful (Bousquet & Le Page, 2004; Klijn et al., 2005). The landscape-level model presented in this study has been used at stakeholder meetings and provided a platform for discussions about land use change. In a related study Huigen (2004) mentions the use of his multi-agent model in a policy context as well. The outcomes of the multi-agent settlement model were a new entry point to discuss a highly sensitive policy issue. The San Mariano government is aware of the increasing land scarcity due to the high population growth, but never looked upon it from the perspective in which spatial differences in population growth and land scarcity are related and (partly) explained. Furthermore, discussing the model outcomes at stakeholder meetings raised awareness that these issues should be quantified to explore alternatives.

Another important issue in the use of modeling results is the validity of the results. Model validations in other case studies have indicated that uncertainty in land use

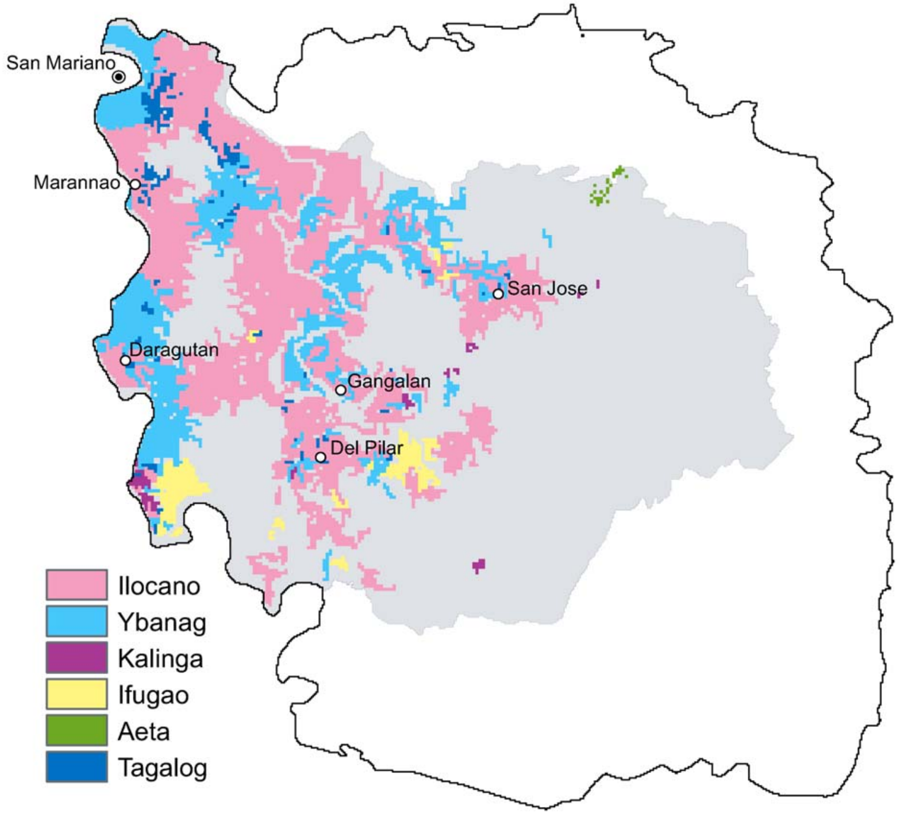

Fig. 7. Simulated pattern of land occupation by different ethnic groups in 1999.

simulations is high (Pontius & Malanson, 2005; Pontius, Huffaker, & Denman, 2004; Wear & Bolstad, 1998). High levels of uncertainty are unavoidable in models of complex integrated systems, but require an adequate presentation and communication of the results to stakeholders. Validation is not only useful to judge the predictive capacity of the models but also to identify failures to correctly simulate the system dynamics and assess the validity of our current understanding and theories (Couclelis, 2001). However, validation requires consistent datasets for at least 2 years which are lacking for the case studies presented in this paper. Although validations of the CLUE model have shown that the model is generally able to produce reasonably accurate predictions (Kok, Farrow, Veldkamp, & Verburg, 2001; Pontius et al., 2005; Verburg et al., 2002) a case study-specific validation is needed to make any inferences about the validity of the presented models and appropriately inform the users of the results.

Conclusion

This paper has discussed and illustrated the role of land use change modeling in providing information useful in planning and management of protected areas. Different model approaches do not necessarily answer similar research and policy questions.

In order to make efficient use of the capabilities of land use change modeling it is essential to closely consider the questions and insights the modeling effort is aiming at, the potential capabilities of the model approach and the specific scale of application. Furthermore, the choice of model type also depends on the availability of data and resources. The construction of the landscape-level simulation model required an in-depth insight in the processes prevailing in the area while the national-level modeling approach is based on readily available national-level data sources. The different modeling approaches can also be used in a 'research chain' in which the national scale modeling is used to determine the influence of national or even transnational processes on the pressure on land resources in a regional case study. At the landscape level a more detailed exploration could be made using a spatial model to identify the trajectories of landscape change and the possible risks for the protected area.

Each scale of analysis requires a different modeling approach that leads to different insights in the land use change processes and addresses different stakeholders. It is no easy task to integrate the results over different scales and address all aspects of the system; no type of framework is as yet able to do so. Therefore, it is more important to value the complementarities of the results at different scales in providing insights in different aspects of the complex system under study. Models should clarify the issues in the debate of protected areas planning and management, facilitate a discipline of analysis and discourse among stakeholders, and provide some type of advice on different policy options (Couclelis, 2001). This paper has shown that adequate modeling tools are being developed in the LUCC community to inform the decision making process in such a way. Challenges for the near future lie in the strengthening of the frameworks separately, the development of overarching insights possibly leading to partial integration, and the improvement of application of the approaches in concrete policy contexts.

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