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Review

From land cover change to land function dynamics: A major challenge to improve land characterization

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ABSTRACT

Land cover change has always had a central role in land change science. This central role is largely the result of the possibilities to map and characterize land cover based on observations and remote sensing. This paper argues that more attention should be given to land use and land functions and linkages between these. Consideration of land functions that provide a wide range of goods and services makes more integrated assessments of land change possible. The increasing attention to multifunctional land use is another incentive to develop methods to assess changes in land functions. A number of methods to quantify and map the spatial extent of land use and land functions are discussed and the implications for modeling are identified based on recent model approaches in land change science. The mixed use of land cover, land use and land function in maps and models leads to inconsistencies in land change assessments. Explicit attention to the non-linear relations between land cover, land use and land function is essential to consistently address land change. New methods to map and quantify land function dynamics will enhance our ability to understand and model land system change and adequately inform policies and planning.

1. Introduction

Land use and cover change have been identified as one of the prime determinants of global change with major impacts on ecosystems, global biogeochemistry, climate change and human vulnerability (Foley et al., 2005). Up to the 1990s land use and land cover change were mainly studied from a disciplinary perspective. The need for interdisciplinary approaches to fully understand the interactions within the land system has, more recently, led to the emergence of the new interdisciplinary field of land change science (Rindfuss et al., 2004; GLP, 2005; Turner et al., 2007). New tools and techniques, often based on the synergetic use of disciplinary theory and knowledge, have increased our ability to monitor and explore changes in land use and land cover. Advances in remote sensing and land inventory techniques enable land scientists to make an assessment of current land resources, identify ongoing land cover change processes and identify hot-spots of change (Herold, 2006). New sensors provide increasing spatial detail, global datasets of land cover have become available (Hansen et al., 2000; Achard et al., 2002) and some regions with rapid ongoing land cover changes are monitored with high temporal resolution (e.g. the PRODES and DETER projects in Brazil (Shimabukuro et al., 2000)). Monitoring of land use and land cover change also includes local case studies in which the processes of change are studied from a sociologic and anthropogenic point of view providing insights in the local drivers and processes. Such case studies may be generalized in meta-analysis in order to identify common patterns and processes (Geist and Lambin, 2002; Keys and McConnell, 2005; Rudel, 2005). Models have proven to be an important tool, both to conceptualize and test our understanding of the role of different drivers in land use and land cover change and to explore scenarios of possible future developments (Parker et al., 2003; Verburg, 2006; Verburg and Veldkamp, 2005; Matthews et al., 2007). In communicating scientific understandings of land change to policy makers and other stakeholders scenarios of alternative trajectories of land change have become widely accepted (Busch, 2006; Verburg et al., 2006b).

A wide variety of land use and land cover change models have been developed to serve the different processes, scales of analysis and research questions (Verburg et al., 2004; Heisterman et al., 2006; Matthews et al., 2007). While the simultaneous development of different modeling approaches has stimulated advances in modeling, most approaches are complementary and targeted at specific scales or issues. Levels of complexity range from models representing decision making of individual actors and actor-interactions to simple transition matrix extrapolations. In spite of

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the large progress in simulation techniques and data, uncertainty levels remain high and the predictability of land use and land cover change in most instances low (Pontius et al., 2008), indicating the need to further improve our understanding and characterization of land change.

One of the main challenges in monitoring, modeling and communicating land change is the relation between land cover, land use and the provision of goods and services by the land system (land functions). Many studies have assessed the consequences of land use and land cover change on different socio-economic and environmental conditions as a post-analysis or impact assessment, e.g. by a series of indicators (Verboom et al., 2007). However, in reality the functionality of the land is intricately linked to the land cover (Walz et al., 2007). A change in the provision of goods and services by the land is often not just a result of land cover change but an important driving factor of future land cover dynamics as well. The Millennium Ecosystem Assessment has requested specific attention for the way in which land cover change and ecosystem functioning are linked (Nelson et al., 2006). Such assessments are difficult because there is no one-to-one relation between land cover and functionality. Functionality is often determined by both local and contextual factors synchronously. In addition, land function may not be observed and monitored by standard techniques used in land cover observation. In many cases land function may drastically change without any change in land cover and vice versa. Attempts to quantify land functions based on land cover information are often limited since land cover is not always a good indicator for the actual functions performed by the land at that location. Therefore, impact assessments based on current monitoring and modeling techniques are often limited to land functions that can be quantified based on the land cover (change) map (Metzger et al., 2006; Kienast et al., under review).

This paper will discuss the challenges faced by land scientists to move beyond the analysis of land cover towards a focus on land use and land functions. The paper will first discuss the needs and challenges of moving beyond land cover as a starting point of land change science. The following sections discuss this transition in terms of, respectively, monitoring and modeling techniques. Examples from a number of studies are used to illustrate this challenge and identify a number of promising approaches.

2. From land cover to land use and land function analysis

It is important to distinguish the different ways in which we may characterize the land surface in land change studies (Fig. 1). Commonly we characterize the land surface by distinguishing different land cover types (Jansen and Gregorio, 2002). Land cover addresses the layer of soils and biomass, including natural vegetation, crops and human structures that cover the land surface. Land cover is thus directly observable, both in the field as well as from remote sensing images. Land use in contrast refers to the purposes for which humans exploit the land cover (Fresco, 1994; McConnell and Moran, 2001; Lambin et al., 2006) and includes the land management practices. Land use is not always easily observable, although, in many cases, land use may be inferred from observable activities (e.g. grazing) or structural elements in the landscape (e.g. the presence of logging roads). When different land uses are systematically linked through either temporal (e.g. crop rotations) or spatial interactions we are dealing with land use systems. Detection and analysis of land use systems are often impossible based on land cover observations only, supplementary socio-economic information is needed to make a good assessment of land use system changes possible (Kruska et al., 2003). At the level of the landscape a myriad of different, interacting land use systems may be present supplying a wide variety of goods and services to society. The capacity of land to provide goods and services is referred to as land use functions or ecosystem functions (de Groot, 1992, 2006; MEA, 2005; Wiggering et al., 2006). In this paper we will use the term land functions when referring to the goods and services provided by the land use systems and ecosystems within the landscape. Land functions not only include the provision of goods and services related to the intended land use (e.g. production services such as food and wood production) but also include goods and services such as the provision of esthetic beauty, cultural heritage and preservation of biodiversity that are often unintended by the owner of the land (MEA, 2005). The provision of such 'unintended' services is also the main reason why the concepts of land use and land management are insufficient for land characterization since these are specifically related to the intended use of the land. A classification of different types of land functions is presented by the Millenium Ecosystem Assessment (MEA, 2005).

Although the capacity of the land to provide goods and services is related to land cover, many other factors, including the spatial arrangement and temporal intensity of land use in the landscape, may be important. Land function change may therefore not only result from local changes in land cover, but can as well be the result of changes in the broader context of the location without changes in land cover at the location itself (e.g. due to isolation of a nature reserve).

Common observation techniques and available maps and spatial datasets provide little information about the spatial variation in land functions. Most data and land classification schemes are limited to land cover or an inconsistent mixture of land cover and land use classes (often referred to as 'land use/cover') depending on our ability to derive land use information from land cover data (Jansen and Gregorio, 2002). The different uses of grassland (grazing, cutting or natural grasslands) provide an example of the limitation to derive information on land use (system) or land function from land cover data based on satellite images. The spatial and temporal dynamics in grazing (e.g. pastoral land use systems) and the many different land use systems related to grassland are a cause of the non-linear relation between grassland and its functions. This causes large uncertainty in estimates of global grassland areas used for grazing and the characterization of land use systems in grassland areas and their dynamics (Kruska et al., 2003). Small differences in actual land use may cause large differences in land cover and land function. Many extensive grassland areas or abandoned croplands are still used for occasional grazing with very low intensity. Such very extensive grazing practices avoid the natural succession of these lands towards shrub land or forest and may preserve the important function of such (semi-)natural grasslands to conserve (agro-)biodiversity values (Quetier et al., 2005; Marini et al., 2008). Similarly, while fire has dramatic consequences for forest land cover, fire occurrences may have little impact on savannah vegetations and may even be seen as a means to avoid land cover change and biodiversity loss due to bush encroachment (Bucini and Lambin, 2002).

The importance of land function change is illustrated by two examples of land function change processes of global importance. The first example concerns the marginalization of agriculture and associated land abandonment. Accurate estimates of the extent of this change are not available due to the problems faced in observing land abandonment by remote sensing. While agricultural statistics indicate strong decreases of agricultural areas these are, in many cases, not observed in data derived from remote sensing. Information on the effects of decreasing agricultural area for the development of rural areas is essential for policy makers involved with agricultural policy and rural development. One of the reasons for not being able to observe the ongoing changes in land use by remote sensing is the use of 'abandoned' grasslands for other functions of which especially horse-boarding is very important. In the peri-urban areas of Western Europe large areas of grasslands on

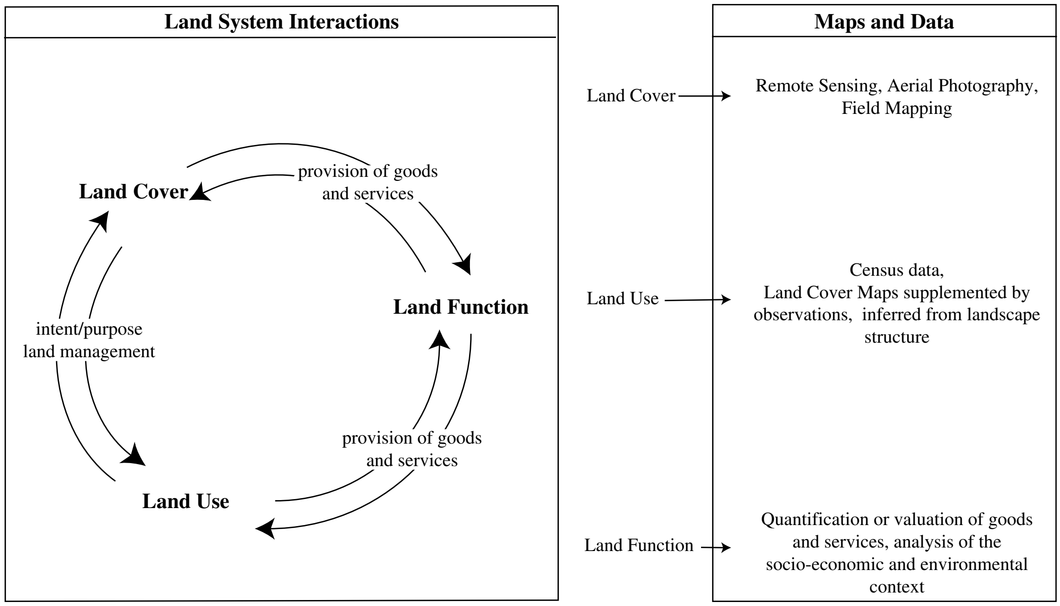

Fig. 1. Representation of the relation between land cover, land use and land function and possible methods to collect spatial data.

former farmland are used for horse-boarding and horse-riding facilities ('horsi-culture'). Although the land cover in these areas remains the same, this has large implications for the functioning of the land and the rural economy. It provides alternative sources of income for farmers who have changed their agricultural practices to facilitating horse-boarding and it may have an impact on the character of the landscape through changes in landscape structure and many artificial elements (fencing, buildings). Because in many countries hobby-horses are not included in agricultural statistics the extent and areas used for this type of land function are largely unknown. Other alternative uses of abandoned land include all kinds of hobby-farming. Also outside the peri-urban areas the process of land abandonment is poorly represented in land cover data. Many authors have reported large declines of agricultural areas in Europe's mountain areas (MacDonald et al., 2000; Etienne et al., 2003; Tasser et al., 2007). These mountain areas are facing two related trajectories of change: part of the meadows is more intensively used, while other parts have been converted to pasture or have been abandoned (Mottet et al., 2006). These changes in intensity and the actual use of the grasslands, either for pasture or for hay-making are not observable by remote sensing but can have large implications for other functions present like the provision of a habitat for a typical vegetation and botanical composition (Hochtl et al., 2005; Tasser et al., 2007). Measures of intensification and abandonment of extensively uses areas both lead to a decrease in the number of species (Tasser and Tappeiner, 2002). Fig. 2 indicates the areas of agricultural abandonment in Europe based on land cover data (derived from remote sensing interpretation of the CORINE database (EEA, 2005; Haines-Young and Weber, 2006)). In a small number of countries the 'hot-spots' of land abandonment on the land cover map correspond to areas frequently cited in literature as facing abandonment (e.g. the Italian mountain areas (Falcucci et al., 2007)). However, in the larger part of Europe the mountain areas that are mentioned in literature as 'hot-spots' of agricultural abandonment do not appear in this map, examples include the French and Spanish Pyrenees (Poyatos et al., 2003; Mottet et al., 2006), Central Massif area in France (Etienne et al., 2003), Austrian alps (Tasser et al., 2007), German mountain areas (Reger et al., 2007) and most of the 24 mountain areas reported by MacDonald et al. (MacDonald et al., 2000).

The second example of land function change is found in many landscapes in developing countries: the intensification of mixed farming systems. Mixed farming or integrated crop–livestock systems are defined as those in which crop and livestock production activities are managed by the same economic entity, such as a household, with animal inputs being used in crop production and crop inputs being used in livestock production (Udo and Cornelissen, 1998; Williams et al., 2000). It is a risk-coping strategy, with livestock providing an important avenue for farm diversification and consumption smoothing. As demographic pressure increases or new market opportunities arise, more intensive modes of agricultural land management that involve increased use of labor per unit of land are adopted. These changes are characterized by changing linkages between crop and livestock production. Land

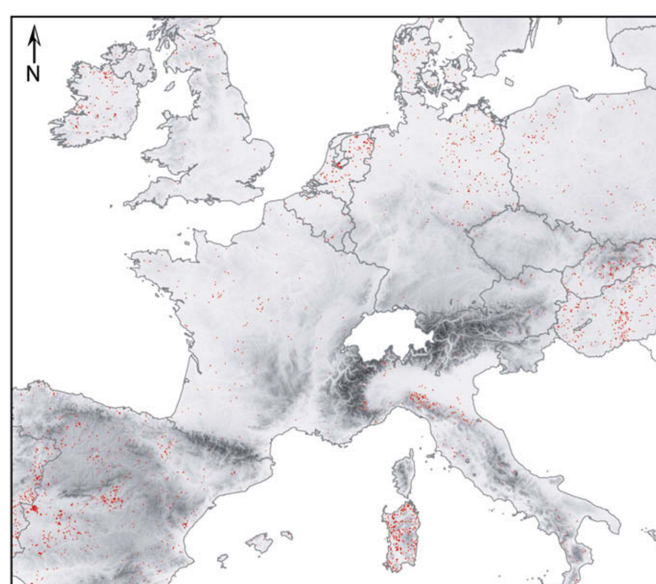

Fig. 2. Location of agricultural abandonment (red) between 1990 and 2000 based on the CORINE land cover datasets. Grayshades indicate altitude.

cover data only reveal the crop production component of these systems in which crop and livestock production have mutually interlinked functions. Mixed farming systems are the main system for smallholder farmers in many developing countries and, at the same time, they contain large numbers (over 1 billion) of poor, of which a considerable number depend to some extent on livestock (Thornton et al., 2003). Intensification through improved agricultural productivity in Africa under changing conditions is an essential step in combating poverty (InterAcademy_Council, 2004). Therefore, good estimates of the occurrence and spatial distribution of changes in the functioning of these systems are needed to target research and policy to promote crop–livestock synergies in a manner, which facilitates expansion of food production, and can sustain or even increase land and labor productivity under conditions of severe resource competition. The land function in relation to the local characteristics of the land and the environmental and socio-economic context determines what development strategy is most appropriate. A better understanding of the spatial heterogeneity in the interacting land functions in these mixed farming systems beyond the traditional farm-level research is essential to provide a guide to subsequent and more focused investigations (Jagtap and Amissah-Arthur, 1999).

Both the above examples indicate the difficulty of characterizing land use and land function change based on available datasets of land cover. Land use characterization is also insufficient in case of land functions that are the unintended result of land use or that emerge from a specific land cover configuration such as the land functions 'provision of scenic landscape' or 'preservation of cultural heritage' (Benjamin et al., 2007; Soliva et al., 2008). Changes in such land functions may have a large impact on the rural economy and the functioning of the land system: increasing tourism in formerly rural areas in the Mediterranean region of Europe provide the potential for alternative employment outside agriculture but does, at the same time, put large claims on water resources (Valenzuela Montes and Mataran Ruiz, 2008). Intensification of agricultural productivity can provide improvement in food security, but without incentives for changes towards more sustainable land use forms intensification will lead to increased rates of nutrient depletion and soil erosion. Information on the spatial distribution of land functions and their dynamics in time is essential to avoid future sustainability problems. Knowledge about the (potential) land functions of different region types is also of prime importance for identifying alternative regional development trajectories, e.g. in case of a declining agricultural sector or unsustainable forest management practices. The increasing encouragement of multifunctional rural areas as a means to deal with rural change and sustainability issues can only be efficiently encouraged by targeted policies if more information about land functioning is made available (Rizov, 2005; Wiggering et al., 2006; Slee, 2007; Jongeneel et al., 2008). Chan et al. (2006) illustrate for the central coast ecoregion of California that a proper characterization of land functions through mapping and quantification offers scope for identifying valuable synergies between land functions through systematic planning.

3. Methods for mapping and quantifying land use and land functions

Land cover can be a cause, constraint or consequence of land use (Cihlar and Jansen, 2001). It is exactly this mutual interaction that makes it difficult to link land cover directly to land use. Some land uses, such as the use of land for residential purposes, directly lead to a change in land cover (built-up land) and a one-to-one relation between land use and land cover is apparent. Mapping of land use is in this case possible based on land cover information. In the case of many other land uses it is not possible to base land use maps directly on land cover maps. In those situations additional information is needed. An example of an approach to map land use is provided by Cihlar and Jansen (2001) in a case study for Lebanon. As much as possible direct links between land cover and land use were established. In case a direct link did not exist Cihlar and Jansen used either additional variables such as altitude or maps of irrigated areas and expert-knowledge to translate the land cover map into a land use map. Although this method proved to be successful in determining the spatial extent of a number of different land uses, it is restricted to land uses that are closely related to differences in land cover and (observable) biophysical conditions. When dealing with more subtle differences in land use more information on the actual determinants of land use is needed to allow mapping the spatial distribution. In most cases detailed field surveys and information on the actual management practices are needed. Such surveys cannot be conducted for large regions without enormous financial and time investments. For land functions the situation is more complex given the importance of the context of the location in its ability to supply goods and services that are often not directly observable. Therefore, alternative methods have to be developed to actually map and quantify land functions. Most current efforts to map land functions or ecosystem services are based on observable or modeled proxies for the functions but acknowledge the limitations of available data to do so (van Jaarsveld et al., 2005; Chan et al., 2006; Naidoo et al., 2008). Two examples of mapping exercises that go beyond traditional land cover maps are presented. Both approaches use additional information concerning the actual use of the land to create a map of land use systems that integrates information on land use and land cover. The first approach describes the construction of a map that explains the distribution of various land use systems across the Kenyan highlands while the second example describes global land use in terms of anthropogenic biomes. The definition of such anthropogenic biomes is a first effort to move towards a classification system in which land functions are explicitly accounted for.

3.1. Mapping land use systems in the Kenyan highlands

The Kenyan highlands are an area of intensive farming with a high variety in farming systems and associated land uses (Staal et al., 2002). Land uses vary from grazing cattle to coffee plantations. Land cover maps do, however, not show the full diversity of land uses. The high resolution AFRICOVER (http://www.africover.org) land cover map based on remote sensing images classifies the larger part of the area cropland. Although it is likely that the larger part of the area will remain under agricultural use in the future, large changes in farming systems and land use are taking place due to processes including the increasing population pressure and climate change (Olson et al., 2008). The analysis and modeling of these changes require more detailed information and spatial data describing the diversity in land use systems. A method was developed to map and describe this variation (Staal, 2005). This method starts with the classification of the diversity in land use into a number of land use systems. Land use systems are traditionally described at farm-level (Kobrich et al., 2003). For large regions it is not possible to classify all individual farms and link the land managed by a particular farm to the farm itself (Rindfuss et al., 2003). However, farming systems are often linked to the environmental and socio-economic context of a location. This information can be used to map and model the dynamics in these systems at regional scales.

Based on a large sample of household level data (interviews) a characterization of six farming systems in terms of resource use, enterprise pattern and livelihood characteristics was made. Hereafter logit models that explained the occurrence of the different farming systems were estimated using contextual information on socio-economic conditions (census data) and environmental conditions such as accessibility, land cover, landscape and soil characteristics. All independent variables were available for the whole region with sufficient spatial resolution from existing maps and databases. The estimated relations between the contextual variables and the land use systems were used to predict the occurrence of the different farming systems across the region resulting in a land use system map for the entire Kenyan highlands (Fig. 3). The map was validated by field checks including rapid rural appraisals to identify the farming system types in the field.

3.2. Mapping land functions at the global level

Although global land cover maps have greatly enhanced our capacity to monitor and assess global change issues, current maps are largely insufficient to adequately address the actual impacts of global environmental change. Different efforts have been undertaken to translate land cover observations into land use maps by combining the land cover maps with agricultural census data describing the agricultural use of the observed land cover (Erb et al., 2007; Goldewijk et al., 2007; Ramankutty et al., 2008). However, large regional differences in farming systems, ecosystem functioning and use of grassland areas can lead to largely deviating responses to global climate change, policy impacts and vulnerability of people in case of environmental change. A recent study by Naidoo et al. (2008) attempted to map ecosystem services at the global level. The authors could only find proxies for four ecosystem services and even these data were considered imperfect. An alternative approach that accounts for some of the differences in land function at the global level is presented by Ellis and Ramankutty (2008). Globally they have defined 18 different so-called anthropogenic biomes or 'anthromes', which represent globally significant patterns of direct human interaction with ecosystems. Each of these biomes shares a common level of interactions between humans and the environment, examples include 'dense settlements', 'pastoral villages' and 'populated rainfed croplands'. Each of these biomes consists of a heterogeneous landscape mosaic combining a variety of different land covers. Through some of this heterogeneity might be explained by the relatively coarse resolution of the analysis, a more fundamental explanation is that human–environment interactions lead to different mosaics due to natural variation in terrain, human enhancement of the natural heterogeneity by concentrating activities at the most productive locations and heterogeneity caused directly by the specific activity types of the considered biome (Ellis and Ramankutty, 2008). Due to its focus on human–environment interactions the anthropogenic biomes are better proxies for the land functions of a particular location than land cover by itself. Besides the use of land cover (derived from Remote Sensing) and (agricultural) land use data (census data) also information concerning the spread of human population was used to construct the map. The human population maps are based on downscaled census data using remote sensing, road network and elevation data (Dobson et al., 2000).

The use of an anthropogenic biome map instead of a conventional biome or land cover map has major advantages in land change science given the better representation of the human–environment interactions and its intensity that cannot directly be observed from land cover data (Ellis and Ramankutty, 2008). Since land functions are a direct result of human–environment interactions the anthropogenic biomes are closely linked to land functions, e.g. by indicating where land cover types are used for the production of commodities and where no primary goods are produced for human consumption ('wild lands'; (Sanderson et al., 2002)). Such a distinction could not easily be made based on the previously available global land cover maps.

The land use systems and anthropogenic biomes in the two examples address landscape functions directly related to the intent of the land use, such as the production of agricultural

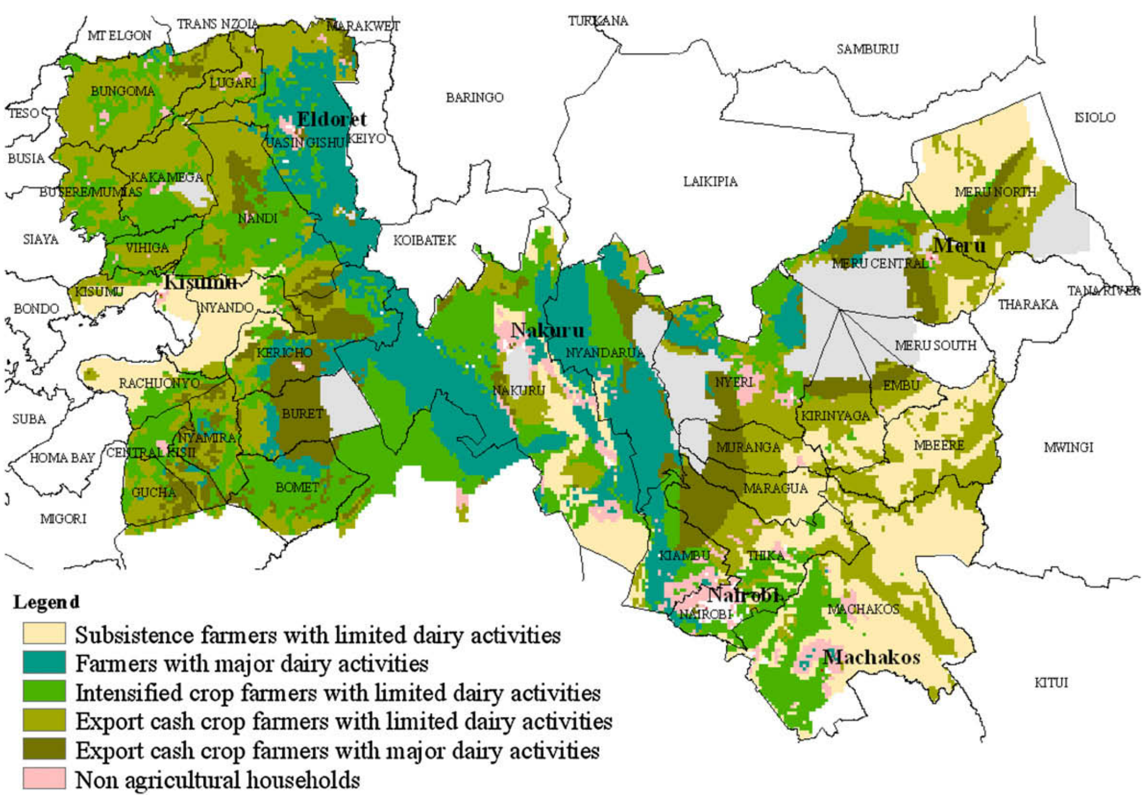

Fig. 3. Predicted spatial distribution of farming systems for the Kenyan Highlands (Staal, 2005).

commodities and are still closely related to land management. The situation is more complicated in case of land functions not related to commodity production, such as water retention (agricultural), biodiversity and landscape esthetics. These functions emerge from land system characteristics such as the landscape structure, land use history and the spatial (multi-scale) arrangement of land use systems across the landscape. Inherently, it is very difficult to quantify and map these services. The quantification of this type of land functions is, however, an important task for land change science (Costanza, 2003; MEA, 2005; Daily and Matson, 2008). In ecological economics various attempts have been undertaken to quantify such functions in monetary terms. Costanza et al. (1997) calculated the global value of ecosystem services by directly assigning monetary values to land cover types while Hein and Gatzweiler (2006a) and Naidoo and Ricketts (2006) calculated the potential monetary value of ecosystem services based on potential benefits to the economy. Other studies have, for recreational functions, quantified the potential value based on demand and 'willingness to travel' measures (Hein et al., 2006b; Hill and Courtney, 2006). Willemen et al. (in press), Gimona and van der Horst (2007) and Egoh et al. (2008) present methods to map and quantify the spatial extent of land functions using observable proxies for a range of land functions. The occurrence of rural tourist accommodations or the amount of tourists counted in a certain region may serve as a proxy for the land function 'provision of attractive landscapes for tourism'. Associations of the location of such proxies with land cover (pattern) and socio-economic, accessibility and landscape characteristics are used to explore the spatial extent of these land services similarly to the approach described in the example for the Kenyan highlands.

Insight in the spatial variation in the capacity of the land to provide such (unintended) services and its determinants is important for spatial planning and regional policy (Chan et al., 2006; Gimona and van der Horst, 2007). In the past land functions such as biodiversity conservation, esthetic value and recreational values were often the unintended by-product of rural land use; more recently, spatial planning and rural policies are aiming at protecting and strengthening these functions in many regions. Land use changes such as agricultural intensification and the enlargement of the scale of farming are a major threat for the provision of these functions by rural areas (Foley et al., 2005; Jackson et al., 2007). Targeted policies and spatial planning can help to strengthen these land functions when sufficient insight is available on the options and constraints of the land to provide these functions.

4. Implications for land change models

The limitations of most data to quantify the spatial location and variation in land functions are a main problem for model based explorations. Lack of data directly influences our ability to explore changes in land function beyond changes in land cover. Also when the interest of the model is limited to land cover change itself modelers are often faced with the need to link land function and land cover. The proximate causes of land cover change are directly related to demands for certain functions, e.g. the demand for agricultural commodities or demands for recreational areas. Most land change models convert the demands for commodities and services into change in land cover areas. These land cover changes are allocated within a spatial representation of the landscape (e.g. (Rounsevell et al., 2005; Sohl et al., 2007; Verburg et al., 2008)). Demands for commodities are often determined by (multi-)sectoral approaches and are expressed in the units of the goods or service under consideration, such as agricultural production. The conversion into land cover change is not always straightforward. In case of agricultural commodities farming system characteristics such as multiple-cropping, intercropping and other management practices need to be accounted for. Expansion of arable area is only one possible way of fulfilling an increasing demand for agricultural commodities. In many cases intensification by means of increasing inputs, efficiency or cropping intensity are more likely means of fulfilling the demand. Similar considerations apply to forestry. Increasing wood demands do not necessarily lead to deforestation but in many cases to forest degradation or changed management practices which are difficult to detect using remote sensing (Lambin, 1999). Most land change models focusing on deforestation are only capable of addressing complete deforestation and ignore forest degradation (Nelson and Geoghegan, 2002). Demands for recreation can only be directly linked to land cover as far as these concern special facilities such as camp sites or attraction parks. However, most recreation takes place as part of a multiple functionality of the land depending on the attractiveness of the landscape and nearness to tourist attractions.

The difficulty in translating demands for commodities and services in land cover claims becomes even more apparent when the demands are based on economic (commodity) models while the spatial allocation is based on land cover change models (Verburg et al., 2008). Economic modeling approaches traditionally rely on agricultural census data with a strong link to the actual land use practices. Most spatial land cover change models are using land cover maps based on remote sensing as a starting point (e.g. (Pontius et al., 2001; Wu et al., 2006; Evans and Kelley, 2008)). Large inconsistencies between agricultural statistics and cropland areas identified by remote sensing are common (Verburg et al., 2006a; Ramankutty et al., 2008). Census data often provide an incomplete view on land use by only reporting the economic sectors and may suffer from sampling problems, underreporting due to linkages with the tax system or over reporting in order to inflate achievements (Smil, 1993; Frolking et al., 1999; Verburg et al., 1999; Xiao et al., 2003). Remote sensing data may suffer from misinterpretation and spatial and thematic inaccuracies (Castilla and Hay, 2007). Several case studies that analyzed different data sources for the same area have indicated deviations between the data sources used (Bach et al., 2006; Fassnacht et al., 2006; Verburg et al., 2006a; Nol et al., 2008). Reasons for such deviations are also related to the spatial resolution of remote sensing which is often inadequate to include all kinds of small or linear landscape elements (Ellis et al., 2006). This effect may be enhanced by aggregation of the data (Moody and Woodcock, 1994; Ozdogan and Woodcock, 2006; Schmit et al., 2006). An analysis of aerial photographs of a number of randomly chosen cropland areas within Europe revealed that between 3 and 20% of the total land area in these landscapes is occupied by roads, water infrastructure, buildings and farmyards and small landscape elements such as hedgerows, tree lines, stony outcrops, etc. (not published results of the EURURALIS project; http://www.eururalis.eu). Examples that indicate the extent of such small-scale landscape features for two areas are shown in Fig. 4. The pan-European land use database based on remote sensing with a resolution of 100-m (CORINE database (CEC, 1994)) represents these areas as completely occupied by agricultural land cover. Using remote sensed data at this resolution in land cover models will certainly lead to a structural large overestimation of the agricultural land area. Overestimation of cultivated areas in remotely sensed data may lead to overestimation of potential food production capacities or underestimation of land use intensity. It is important to realize that structural differences between data sources may be much larger than the change in land cover over a period of one or more decades, hampering the validation of models (Pontius et al., 2008).

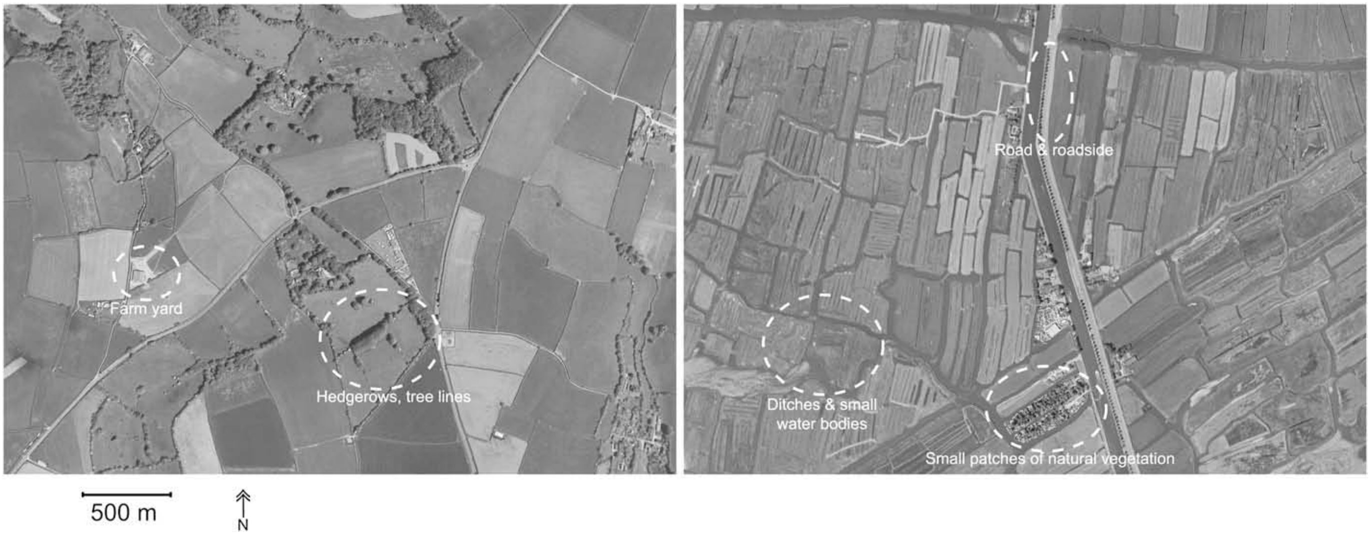

Fig. 4. Examples of landscape composition in two areas (left: South-West UK; right: North-West Netherlands) that are entirely used for agriculture according to remotely sensed land cover datasets at 100 × 100-m resolution (CORINE database, CEC, 1994). Landscape elements that cause a lower actual surface area of agriculture are indicated (images based on Google Earth, accessed January 2008).

5. Discussion and conclusions

Land cover change has always had a central role in land change science (Turner et al., 2007). This central role is largely the result of our capacities to observe land cover directly or indirectly through remote sensing techniques. This paper has argued that more attention should be given to the actual land use and land functions and linkages between these (Fig. 1). Although more attention for land use characterization will certainly improve our understanding of the land system, a further characterization of land functions is needed given the importance of goods and services that are not directly related to the specific intend of the land management. A better understanding of the interactions between land cover, use and function and methods to map and quantify land use and land function will also benefit our ability to properly model land changes. The fact that land function cannot always be observed directly will, however, continue to limit our capabilities to base our analysis on land use and land function directly. A proper representation of land function will always require additional data beyond land cover observations which, in many cases, can only be achieved at local scales of analysis. Recent studies have indicated that the mapping of land functions based on proxies provides options to actually map and quantify land functions (Egoh et al., 2008; Naidoo et al., 2008; Willemen et al., in press). However, it is questionable if the identification of a number of specific land functions, such as the provision of esthetic beauty, will be possible beyond the local to regional scale as used in case study research (Hunziker and Kienast, 1999). In this situation methods to properly translate case study findings to larger regions are helpful to use case study results on land functions for larger regions and policy making. Often case studies are selected being representative for a larger region, but this region is not indicated and the case study selection may have been arbitrary chosen or based on practical considerations. Indication of the representativeness of case study results should therefore be a requirement for publishing.

The increasing attention for multifunctionality of the land (Mulloy and Ottitsch, 2000; Fry, 2001; Holmes, 2006; Wilson, 2008) necessitates the development of methods and tools to map and quantify the different functions across the landscape. Land cover based methods are clearly insufficient when multiple functions are considered. Straightforward analysis of land cover change impacts on multifunctionality ignores the emergence of land functions from land system interactions and is therefore mostly inadequate. Multifunctionality is not only important in densely populated areas with high claims on land resources. Also other areas have multiple functionalities that are important for functioning of the land system, e.g. in terms of providing regulating services such as water retention or carbon sequestration. Policy can benefit from identifying 'hot-spots' of synergies and conflicts between land functions (Chan et al., 2006; Gimona and van der Horst, 2007; Willemen et al., in press).

In addition, a better understanding of the interactions between land use and land function and methods to map and quantify land use and land function will also benefit research organizations, the donor community and development oriented NGO's in several ways. The characterization and spatial mapping of land function change can help to identify priority areas for intervention and context specific investment opportunities and options. Mapping and quantifying land functions can assist the determination of where the greatest opportunities exist and which type of intervention strategy is suitable under the prevailing circumstances. As well it can help in the identification of hot-spots of change or vulnerability.

The challenge to move the focus of land change science from land cover to land use and land function requires the development of new data, methods and an even further integration of the disciplines involved in land science research. The progress of the land change community to develop new data, methods and models within the past decade indicates the innovative capacity of the community (Rindfuss et al., 2004; Turner et al., 2007). We are therefore optimistic that the land change community will be capable to meet the challenges identified in this paper.

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