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The integration of crop rotation and tillage practices in the assessment of ecosystem services provision at the regional scale

Lars Koschke[a,*], Christine Fürst[b], Marco Lorenz[a], Anke Witt[a], Susanne Frank[a], Franz Makeschin[a]

[a] Department of Soil Science and Site Ecology, Dresden University of Technology, Pienner Str. 19, 01737 Tharandt, Germany
[b] Center for Development Research, Department of Ecology and Natural Resources Management, University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany

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ABSTRACT

The provision of ecosystem services at the landscape level can be significantly influenced by land management practices. Within an agriculturally dominated case study area in Saxony, Germany, a more detailed land use classification, which includes differentiated information on agricultural management practices, was utilized within the raster-based planning support tool GISCAME. "Management" refers to typical, regional crop rotations and soil tillage practices.

The focus of this research was based on an indicator-based approach to assess ecosystem services and the development of land use change (LUC) and land management change (LMC) scenarios. The EuroMaps Land Cover data set was specifically developed for the case study and included remote sensing information for the general land use classification and terrestrial mapping information. Furthermore, statistical data on detailed regional agricultural land management were included. The raster-based planning support tool GISCAME was then used to simulate scenarios and visualize results. The LUC and LMC scenarios showed that the more detailed land use classification provided better output for the prioritization of planning alternatives. Further it enabled a refined assessment of the provisioning services (i) food and fodder provision, (ii) biomass provision, the regulation services, (iii) soil erosion protection, (iv) drought risk regulation, (v) flood regulation, (vi) returns from land-based production (i.e. the market value of biomass provision), and (vii) ecological integrity. The results of this study support the view that the application of improved management measures, such as conservation tillage, can significantly enhance the provision of ecosystem services (e.g. soil erosion protection and drought risk regulation) at the landscape level. The study also indicates that a combination of strategic LUC, such as afforestation and LMC, might be an effective way to enhance regulating services with acceptable trade-offs regarding provisioning services. Our approach presents a refined foundation for ecosystem services assessment, which is designed to better support regional planning and the provision of information to non-experts in the participatory processes. For transfer into other regions, standardized land use and land management classification will have to be defined.

1. Introduction

1.1. Background

The ecosystem services concept has become a key concept in natural resource management and environmental impact assessment, as a means of connecting human well-being to the degradation and overexploitation of ecosystems and natural resources (Burkhard et al., 2010; Fisher and Turner, 2008). The application of ecosystem services helps to increase awareness that natural ecosystems provide the basis for human well-being, which is a core advantage of this concept. As a support tool it can assist stakeholders and decision makers (land managers, local or regional planning authorities) in developing sustainable land use strategies (de Groot et al., 2010; MA, 2005; Swetnam et al., 2011; TEEB, 2010).

After a period with many conceptual contributions the concept of ecosystem services has now gained increasing acceptance. However, a growing number of authors have identified limitations in application of the concept and the need (i) for integrated and easily applicable assessments in landscape management and land-use planning (Bastian et al., 2012; Burkhard et al., 2009; Fürst et al., 2011; Müller et al., 2011), and the need (ii) to apply the concept in

* Corresponding author. Tel.: +49 35203 38 31377; fax: +49 35203 38 31388.
E-mail address: Lars.Koschke@tu-dresden.de (L. Koschke).

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a practical manner and to overcome difficulties with respect to its implementation (Burkhard et al., 2011; Frank et al., 2012; Menzel and Teng, 2009; Wallace, 2007). While some practice oriented studies have been published, which actually discuss outcomes with regards to their relevance in and implications for landscape planning or regional planning issues, the overall number of such studies remains low (for example Egoh et al., 2007; Fürst et al., 2012; Schetke and Haase, 2008; Scolozzi et al., 2012).

Land cover and land use changes (LCC/LUC) can significantly improve or degrade the provision of ecosystem services (Foley et al., 2005; MA, 2005). Thus, at the regional to global scale, ecosystem services are mostly mapped and analyzed on the basis of land cover/land use (pattern) change (Burkhard et al., 2011; Kienast et al., 2009; Lautenbach et al., 2011; Seppelt et al., 2011; Scolozzi et al., 2012; Willemen et al., 2008). For example, it has been shown that afforestation can be an important measure to enhance soil erosion protection (Witt et al., in press), esthetic value, or biotope connectivity (Frank et al., 2012). The expansion of residential area and land consumption for transport infrastructure leads to a degradation in regulating (e.g. climate regulation, water purification, pollination), provisioning (e.g. biomass, food, freshwater), and cultural ecosystem services (e.g. outdoor recreation) (Kroll et al., 2012; Lautenbach et al., 2011). Analyses of historical LCC/LUC changes and the modeling of possible future trajectories are essential to assess and illustrate the potential of a region to provide ecosystem services. However, the transfer of this information into practical usage can be hindered, as the scale of ecosystem services assessment – and therefore the degree of precision – might not match the level of decision making (Meinke et al., 2006; Scolozzi et al., 2012; Turner and Daily, 2008). The basic problem is the quantification of ecosystem services in required detail, as their provision varies considerably as a function of land cover/land use *and* site conditions such as climate, soil, topography, neighborhood effects, land management practices, and time (Daily and Matson, 2008; de Groot et al., 2010; Meersmans et al., 2008). The supply of ecosystem services tends to be impacted more by land use intensity and land management practices than by actual LCC/LUC (Kroll et al., 2012).

Cropping systems are a common form of classifying agricultural land management (Schönhart et al., 2011a,b; Snapp et al., 2010). They are commonly regarded as an important factor for the sustainability of agricultural systems (Ball et al., 2005). The term cropping system includes management options, i.e. crop rotations and soil management (Sebillotte, 1990). In agricultural landscapes, crop rotations and tillage practices influence a variety of ecosystem services such as yields of agricultural products, water and soil quality, and esthetics (Conrad and Fohrer, 2009; Dale and Polasky, 2007; Snapp et al., 2010). At the landscape scale, they may be important for mitigating the risk to agricultural production from threats such as soil erosion and climate impacts such as droughts. These types of management options are rarely considered in current land use modeling frameworks (e.g. Schönhart et al., 2011b). Hence, the addition of these factors might be beneficial when making an assessment of ecosystem services provision at the landscape scale.

In the project REGKLAM (www.regklam.de), which is being conducted in the state of Saxony located in Eastern Germany, we applied the ecosystem services concept to effectively support the integration of forest and agricultural management planning and regional planning with respect to climate change adaptation. In our study area we have observed only sporadic recent LCC/LUC with a low probability of change in the foreseeable future due to the regulatory framework, landowner rights, etc. Given these limitations, considering LCC/LUC as a primary means of adapting to environmental risks may not be feasible. Therefore, a better alternative for improving ecosystem services provision may be to focus on land management change (LMC), such as the management of crop rotation, tillage practices, and other management options. Previous studies have shown that using general purpose land cover data sets such as CORINE to support land-use or landscape planning is limited by its relatively coarse spatial and thematic resolution (e.g. Weiers et al., 2004; Schmit et al., 2006; Koschke et al., 2012). Therefore, a high-resolution land use data set (EuroMaps Land Cover, EMLC) has been developed by integrating regional crop rotation classes (Lorenz et al., in review) and regional forest types to account for management options in agriculture and forestry (Witt et al., in press).

1.2. Objectives

The overall objectives of our research were to increase the consideration of ecosystem services and integrated management in regional and participatory planning, to provide an approach to quickly compute the effects of alternate potential planning strategies (i.e. LCC/LUC and LMC scenarios) on a range of ecosystem services, and to provide a better foundation for decision support. To this end, in this paper we have developed an approach to assess the provisioning services of (i) food and fodder provision, (ii) biomass provision, and the regulating services (iii) soil erosion protection, (iv) drought risk regulation and (v) flood regulation. Further, we assessed (vi) returns from land-based production (i.e. the market value of biomass provision), and (vii) ecological integrity (which is considered "a prerequisite for providing ecosystem goods and services to humans" (Burkhard et al., 2009)).

Specific objectives of this paper were (1) to identify the assets and drawbacks of the presented assessment approach, (2) to identify land use patterns that enhance the provision of regulating services, improve ecological integrity and involve acceptable trade-offs with regards to provisioning services, and (3) to provide general recommendations for land use alternatives that help to counteract climate change related risks. As a previous attempt to use the common CORINE land cover data set turned out to be unsatisfactory for stakeholders (Koschke et al., 2012), our hypotheses is that a detailed spatial data set, which combines land use and land management, will provide a better foundation for the assessment of ecosystem services and the support of regional/landscape planning.

In this paper, we apply the term *land cover (change; LCC)* and *land use* (*change*; *LUC*) synonymously to refer to the EMLC data set. *Land management* (*change*, *LMC*) is applied to refer to crop rotation classes which can be further differentiated with respect to crop management options (conventional tillage/ploughing and conservation tillage/mulch and no-tillage).

2. Materials and methods

2.1. REGKLAM study region and case study area

The REGKLAM (www.regklam.de) study region is located in the state of Saxony in eastern Germany, and has a total area of approximately 4778 km^2 (Fig. 1). The study region is comprised of three main agricultural production regions: The Saxonian loess belt (NW) with mainly loess soils (*L*), the Saxonian–Lower–Lusatian heathland (NE) with diluvial (sandy) soils (*D*), and the Saxonian lower mountain range (*S*) with deeply weathered bed-rock soils (*V*) (Mannsfeld and Syrbe, 2008). Within the REGKLAM study region, our research focuses on a 4.5 km^2 study in the Großenhainer Pflege, a sub-region situated within the Saxonian loess belt which is characterized by large agricultural holdings with a low number of landscape structural elements (i.e. hedgerow, forest patches; Hanspach and Porada, 2009; Fig. 1). Based on the raster cell size of 25 m^2, the extracted map extract consists of 32,400 raster cells. The sub-set was selected to provide an example for investigating and discussing the effects of the LUC and LMC