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

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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 making improved decisions 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, and (v) flood regulation, the economic service (vi) returns from land-based production, 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.

Key-words: land use planning, benefit-transfer, decision support, land use change, land management change, management scenario, crop rotation, GISCAME

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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). A core advantage of this concept is the increased awareness that natural ecosystems provide the basis for human well-being, and as a support tool to 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., 2011; Burkhard et al., 2009; Fürst et al., 2011; Müller et al., 2011), and (ii) to apply the concept in 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 examples see e.g. Egoh et al., 2007; Fürst et al., 2012; Schetke and Haase, 2008; Scolozzi et al., 2011).

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., accepted), aesthetic 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., 2011; 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; Schönhart et al., 2011b; 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 aesthetics (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 apply 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, and that there is not a high 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 within the existing land-cover framework. Previous studies have shown that using CORINE land cover data as the foundation for land-use planning are limited by its relatively coarse spatial and thematic resolution (e.g. 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., submitted) and regional forest types to account for management options in agriculture and forestry (Witt et al., accepted.).

1.2 Objectives

The overall objectives of our research are (1) to increase the consideration of ecosystem services and integrated management in regional and participatory planning, (2) to provide a quick approach for assessing the synergies and trade-offs of alternate potential planning strategies, and (3) to provide a better foundation for decision support. To this end, we have developed an approach to assess the provisioning services of (i) food and fodder provision, (ii) biomass provision, the regulating services (iii) soil erosion protection, (iv) drought risk regulation and (v) flood regulation, the “economic service” (vi) returns from land-based production, and (vii) ecological integrity. Through analysis of

LCC/LUC and LMC scenarios, land use patterns that enhance the provision of regulating services, improve ecological integrity, and involve acceptable trade-offs with regards to provisioning services should be identified. We aim to provide general recommendations for land use alternatives that help to counteract climate change related risks and we identify the assets and drawbacks of this approach. As a previous attempt to use the common CORINE land cover (CLC) data set turned out to be unsatisfactory for stakeholders, 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). If not otherwise specified, the ecosystem services, the economic service, and ecological integrity are henceforth summarized under the term *ecosystem services*.

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 4,778 km² (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, etc.; 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 scenarios in detail. The forested area of the targeted study area is approximately 4%, while intensively used arable land accounts for approximately 75%. The goal of regional planners is to develop the Großenhainer Pflege towards a landscape that is less sensitive to environmental impacts. Therefore, the sustainable provision of agricultural goods and a significant increase of regulating services are fundamental to achieving this goal. Two potential methods which may be implemented towards this end are afforestation with site adapted tree species to increase habitat connectivity, and developing planning initiatives which will reduce soil erosion (RP, 2009).

Fig. 1

2.2 Application of GISCAME for scenario simulations and visualization of results

For conducting LUC and LMC scenarios, we used the software tool GISCAME (formerly called "Pimp Your Landscape") which combines GIS routines with a cellular automaton and a multi-criteria assessment routine (Fürst et al., 2010a; Fürst et al., 2010b). With GISCAME we assessed and visualized the provision of ecosystem services in the case study area based on the current or simulated land use pattern.

Fig. 2 shows the data processing (see chapter 2.3 for more details) and application of data procedures in GISCAME, beginning with the land use data set and the ecosystem services indicators as the basis for assessment. The resulting value matrix was used in GISCAME to assess the provision of services. The spatial data (DEM, soil data) were used as input for developing scenario layers according to which LUC/LMC scenarios were carried out. We utilized scenario layers with binary coding to distinguish cells that are not affected (value 0) and cells that are foreseen for LUC/LMC (value 1). For example: If a layer of priority areas for afforestation is used, conversion to forest will be conducted for any cell for which 1 has been attributed in the layer.

The assessment of ecosystem services provision potential for the given land use data set included (a) the basic evaluation of single land use classes based on a benefit-transfer approach (value matrix/cell values in GISCAME) (Fürst et al., 2010a; 2010b; 2011; 2012; Koschke et al., 2012). This qualitative evaluation was based on indicator values, whose original values were normalized to a reference scale ranging from 0 (no contribution) to 100 points (maximum regional contribution) to enable a comparison of different ecosystem services with different indicators in a radar chart. (b) A complementary evaluation of the impact of the landscape structure, i.e. configuration and composition of land use classes, corrected the result achieved on the basis of accounting for the land use class dependent cell values within GISCAME (Frank et al, 2012).

Fig. 2

2.3 Land use data set

We utilized the EMLC data set specifically developed for the case study. It included remote sensing information, reference year 2009 for the general land use classification, and terrestrial and statistic information for the regionally specific classification of forest and agricultural land management classes. The EMLC data set has a spatial resolution of 25 m^2 raster cell size and a thematic resolution of 85 classes, of which 32 were forest management classes (Witt et al., accepted) and 31 were agricultural management classes (Lorenz et al., submitted; Fig. 1).

Lorenz et al. (submitted) delineated standardized crop rotations based on statistical references at the field block level (*i.e.* agricultural management unit) between 2005 and 2010. Soil management practices (*e.g.* ploughing, mulching/no-till) were additionally added as eligible attributes that allow for more detailed impact assessment regarding, for instance, water driven soil erosion (C-factor in the USLE) or contribution margin per ha^{-1} a^{-1}. Grassland was integrated into the classification of arable land as crop rotation A-1 (clover monoculture). If the grassland class of the original EMLC data set could not be identified as arable land in the crop rotation classification it was considered to not belong to the arable land class. Thus, two grassland classes exist in the integrated data set: Common grassland and A-1 as part of the crop rotation classification. Forest classes have been defined which correspond to information from the forest inventory (*e.g.* tree species, forest stand types) of the Federal State of Saxony (Witt et al., accepted).

2.4 Ecosystem services assessment approach

The provisioning services (i) food and fodder provision, (ii) biomass provision, the regulating services (iii) soil erosion protection, (iv) drought risk regulation, and (v) flood regulation (MA, 2005), the economic service (vi) returns from land-based production (cf. Koschke et al., 2012), and (vii) ecological integrity (Barkmann et al., 2001; Burkhard et al., 2009) were assessed. The ecosystem services were selected in collaboration with regional stakeholders and to reflect climate change related risks in the study region. Stakeholders wished to include what we call an economic service in order to inform about returns from the production of marketable goods (cf. Koschke et al., 2012).

Each service was assessed through one or two indicators at the land management and land use class level. Indicators were selected based on discussion within the research group and availability of data. Indicator values have been obtained in physical units from measurements or modeling results found in the literature, regional projects, or statistical data. Additionally, if no quantitative values were available, expert knowledge was used (Koschke et al., 2012; Fürst et al., 2012). An overview of ecosystem services, indicators, data sources, and methods is given in Table 1. A complete compilation of applied data, assessment steps, and assumptions can be obtained from Table A.1 (Annex A). In order to derive relative land use type specific values, we utilized – depending on the service – one of three different methodical approaches:

Normalization of ratio scale values (application of one quantitative indicator).

Quantitative indicator values were mapped to the individual land use and land management types to represent their potential to provide the service of food and fodder provision, provision of biomass, soil erosion protection, flood regulation, and returns from land-based production (benefit-transfer approach). In a subsequent step, we normalized these values to the evaluation scale (0 to 100 points). Equation 1 was used if the maximum indicator values represent the maximum potential to provide a service (food and fodder provision, provision of biomass, and returns from land-based production). Equation 2 was applied if decreasing indicator values correspond to an increasing contribution to a service (*e.g.* soil erosion protection, flood regulation).

(1) $$I_{norm} = \left(\frac{I - I_{min}}{I_{max} - I_{min}}\right) * 100$$

(2) $$I_{norm} = \left(\frac{I - I_{max}}{I_{min} - I_{max}}\right) * 100$$

I_{norm} is the indicator value for a given land use type, normalized to a score between 0 and 100, and I is the value of the indicator assigned to the individual land use type. I_{min} and I_{max} correspond to the minimum and maximum of indicator values. Maximum/minimum values relate to highest/lowest values found either in the focus area (yield, contribution margin, evapotranspiration, hemeroby class, number of plant species) or in the literature (C-factor, transpiration coefficient, curve number).

Multi-criteria evaluation (application of two quantitative indicators).

We used the criteria water demand and water use efficiency and allocated indicators for assessing drought risk regulation. Minimum values of water demand (potential evapotranspiration in mm ha^{-1} a^{-1}) were derived from literature for every crop and trees species. Based on regional expert knowledge and data from the Saxon State Office for the Environment, Agriculture, and Geology (LfULG), we assumed the water demand for conservation tillage to be decreased by 10 % in comparison to conventional tillage as a consequence of reduced tillage. We assessed water use efficiency through application of the indicator transpiration coefficient (l kg^{-1} Dry Matter (DM)). An increased transpiration coefficient indicates higher yield relative to the water consumption although the absolute amount of water consumption could be high at the same time (Drastig et al., 2010; LfULG, 2009).

The normalization procedure (cf. Equation 2) was applied to normalize original indicator values of water demand and water use efficiency. Then, we aggregated the two indicators by averaging normalized indicator values prior to an additional normalization to derive relative final scores (Equation 1) ranging from 0 to 100 points. Each criterion contributed to the final value with a weight of 0.5. For a more elaborated description of the aggregation procedure see Koschke et al. (2012).

Ecological connection matrix (for combining qualitative indicator values).

To assess ecological integrity (Barkmann et al., 2001) we used the approach of an ecological connection matrix (Bastian and Schreiber, 1999) to combine hemeroby class, which is the degree of anthropogenic impact (acc. to Blume and Sukopp, 1976) and land use diversity class, which is the ratio of the number of crops or tree species within a land use/crop rotation class and the respective assumed maximum number. We assumed that the ecological value of a land use class increases (a) with decreasing human impact and (b) with increasing structural diversity in space and time. Therefore, *spatial* diversity, the number of tree species according to class description and *temporal* diversity, the number of different crops in a rotation were given equal importance (Table A.1.2) to enable an integration of crop rotation classes in the EMLC data set. The impact of soil management techniques is expressed by the soil management intensity, which directly depends on the number of tillage operations. Thus, conservation tillage was assessed by assigning crop rotation classes under this management option to the hemeroby class “mesohemerob” (low human impact). In contrast, we assigned crop rotation classes under conventional tillage to “euhemerob” (higher human impact).

Table 1

Complementary, we used a GISCAME routine which involves landscape metrics (LMs; cf. Table 1) to assess the criteria landscape fragmentation, landscape diversity, and habitat connectivity in order to correct the results for ecological integrity at the landscape level. Applied LMs were cost-distance analysis (CDA), effective mesh size (Meff), core area of natural land cove types (CAI), and shape index (SHAPE). This correction was necessary to assess important aspects of the land use pattern which is a component of the hierarchical multi-criteria evaluation concept in GISCAME (Fürst et al., 2011; 2012). The original LM routine was developed for the CORINE Land cover 2006 data set. Therefore, we had to adapt it to the EMLC data set according to the methodical steps elaborated on in Frank et al. (2012, p.3).

Table 2

2.5 Development of land use and land management scenarios

We differentiated LUC scenarios, which is afforestation of arable land with Oak mixed deciduous forest > 20% and change towards extensive grassland, i.e. permanent clover (class A-1) and LMC scenarios, meaning change of tillage practice and crop rotation class (Flow chart in Fig. 3). The current land use pattern and soil tillage ploughing at agricultural sites was used as the reference scenario (BAU) (cf. Table 2).

Fig. 3

We based LUC scenarios on a set of layers representing areas suitable or foreseen for adaptation measures related to land use change. These are (1) priority areas for afforestation as delineated in the regional plan (RP, 2009; see Fig. 3a). We used three layers which differed in terms of the affected area (min, medium, max); (2) discharge paths which have been proposed to be extensively used to reduce water erosion and export of soil within the catchment area (Feldwisch et al., 2007; Köthe et al., 2005; see Fig. 3b). Again three alternative layers were applied, discharge paths with high, very high, and extreme concentration of runoff. LMC scenarios were conducted according to (3) areas potentially sensitive to water erosion based on the USLE factors S (slope steepness) and K (soil erodibility) (Wischmeier and Smith, 1978) which we calculated with ArcMap9.3 according to DIN 19708 (2005; see Fig. 3c). We used the digital elevation model (DEM) of Saxony with a resolution of 20 m to calculate the S-factor. For computation of the K-factor we utilized the soil map shape file (1:50,000) of the Saxon State Office for the Environment, Agriculture, and Geology. Data layers were scaled to match the resolution of the land use data set prior to their introduction into GISCAME. We classified the erosion risk according to the Cross Compliance policy (DirektZahlVerpflV, 2004): low risk (S*K <0.1), medium risk (0.1-0.3), and high risk (>0.3). Using this classification, we found that almost the whole agricultural area in the case study area is very sensitive to water induced soil erosion. Hence, tillage practice of current crop rotation classes – of all agricultural sites – was altered towards conservation tillage in order to account for large scale water erosion risk. (4) Given the targets of the German Government to increase the proportion of electric energy generated by renewable sources to 35 % by 2020, an increase of the share of arable land used for energy production of up to 40 % can be expected (BBSR, 2012). Thus, on 40 % of the case study area corn was applied over a theoretical period of ten years, using crop rotation L10 (silage corn – silage corn – silage corn – winter-wheat). (5) Further, we carried out scenarios with diversified crop rotations on 20 % of the cultivated area (acc. to targets of BMU, 2007). We applied crop rotation classes L4 (sugar beet – winter-wheat – silage corn – summer-barley – winter-wheat – winter-barley) and L6 (peas – winter-wheat – winter-barley – potatoes – summer-barley) randomly until 20 % area share was reached. (6) Additionally, we studied the impact of organic farming crop rotations on 20 % of the cultivated area, which is a target of the German National Sustainable Development Strategy (BR, 2012). For this, we applied crop rotations L7 (clovergrass – winter-wheat – silage corn – field beans – winter-rye) and L8 (alfalfa – winter-wheat – potatoes – winter-rye – field beans – winter-triticale).

2.6 Uncertainty analysis

Indicator values that we took from the literature, regional statistics, and the normalization procedure are subjected to uncertainty. Final assessment values can vary considerably within a land use/land management class due to (i) a general transfer error resulting from site specific variation of indicator values as a function of environmental and management conditions and (ii) changing minimum and maximum values to which the normalization approach is sensitive. We performed an uncertainty analysis for BAU and the simulated scenarios to see if the results are robust to the uncertainty in the model. Due to the frequent lack of indicator values that would enable a sound estimation of the range of indicator values per land use class in the study region, we varied indicator values in 1,000 iterations randomly within +/- 30 % around the initial value. The indicator ranges have been established according to common assumptions on the variability of environmental indicators (Strauch et al., 2012). In a subsequent step, normalization and calculation of the final, landscape level assessment value was performed for each of the iterations to derive mean values, standard deviations (SD), and uncertainty ranges of assessment results (Fig. 5, Table 4).

3 Results

3.1 Data gathering results

Table 3 provides an overview on the assessment results of the EMLC data set. For every land use and land management type a relative value could be derived. The assessment matrix reflects that soil surface sealing is an important driver of ecosystem services loss and decline of ecological integrity. Thus, the overall performance of near to nature land use types is much better in comparison to land use types with a high proportion of sealed surface. Lower management intensity in agricultural areas led to a slight decrease of provision services while regulating services and ecological integrity achieved higher value points.

Table 3

3.2 Results of the LUC and LMC scenarios

To discuss the results of the LUC and LMC scenarios (Fig. 4), we will focus on assessment scenarios M-1, M-2, and A-9, as they display the most distinct positive or negative impacts on the provision of ecosystem services. Conversely, we will also focus on scenario A-3, as an example of a scenario resulting in insignificant changes.

Scenarios M-1 and A-9 show the similar potential benefits that large scale conservation tillage and afforestation may provide in terms of regulating services, i.e. soil erosion protection, drought risk regulation, flood regulation, and ecological integrity. These benefits come at the expense of provisioning services, i.e. food and fodder (- 2 and - 17 value points in comparison to the current land use/ management pattern (BAU)), biomass (- 5 and - 1), returns of land-based production (- 2 and - 6) (cf. Fig. 4; Fig. B.1 in Annex B for all scenario results; Table 4, mean values). LMC towards 40 % silage corn (M-2) resulted in the worst performance with regards to soil erosion protection (-19), drought risk regulation (-12), and ecological integrity (-6). Returns from land-based production increased by 5 points in M-2, while in the other scenarios that focused on less intensive land use/management options, a reduction could be observed. The differences observed in A-3 in relation to BAU did not exceed +/- 1 point.

With 5 points range of values, the general performance of biomass provision was relatively constant throughout the different scenarios including BAU since reduced agricultural yields resulting from less arable land could be substituted by wood biomass from forest land. Food and fodder provision, drought risk regulation, flood regulation, returns from land-based production, and ecological integrity ranged between 8 and 14 points. Soil erosion protection with 28 points showed the biggest sensitivity to simulated LUC/LMC.

Fig. 4

Table 4

Box plots resulting from uncertainty analysis show the possible range of assessment values for a 30 % variation of indicator values (Fig. 5). The average variation of scenario values for food and fodder provision accounted for +31 % and -26 % of the mean. Similar variations could be observed as to provision of biomass (+30 %, -27 %) and ecological integrity (+27 %, -25 %). The biggest variation observed was with flood regulation (+51 %, -27 %) and drought risk regulation (+47 %, -30 %). With +13 % and -6 %, soil erosion protection showed the least mean variation, and with 0.4 to 5.8 points also the lowest standard deviation (Table 4). Therefore, in this assessment, soil erosion protection can be considered the most robust. In general, the box plots demonstrate that targeted LUCs/LMCs not necessarily lead to the expected alteration of ecosystem services provision and that specific impacts may widely vary as a function of site specific conditions.

Fig. 5

In all of the LM-based scenario assessments (with the exception of the A-9 scenario), decreased ecological integrity was observed due to predominant characteristic of the agricultural areas considered, which have low natural core areas, large field sizes, a relatively low number of different land use types, and little connected habitat area. This is well reflected in largely constant LM-values (Table 5 and Table B.1 in Annex B). In scenario A-9, LM-based evaluation led to higher scores, primarily because habitat connectivity was greatly strengthened (CDA increased from 3.0 % to 32.3 %) and along with improvements in landscape diversity (SHDI from 0.8 to 1.1 and SHAPE from 1.4 to 1.5). Further, landscape fragmentation was reduced because the CAI of natural areas increased from 2.1 to 26.9 % and the M_{eff} of unfragmented areas increased slightly from 4.0 to 4.3 km². Translating original LM values into value points, scenario A-9 was evaluated with +/- 0 points with respect to landscape fragmentation and landscape diversity. With regards to the criterion habitat connectivity, the basic evaluation result improved by 10 points, so that ecological integrity achieved an overall increment of 10 points. The remaining scenarios were all reduced by 25 points. Thus, LM-based evaluation led to following decrement/increment: BAU: from 32 to 7; M-1: from 43 to 18; M-2: from 25 to 0; A-3: from 32 to 7; A-9: from 39 to 49 (Table 5). These results make obvious to the user the importance of aspects such as composition and configuration of the land use pattern.

Table 5

4 Discussion

4.1 LUC and LMC scenarios

Results show a substantial increase of soil erosion protection by application of conservation tillage as compared to conventional ploughing, which suggests that the model was implemented correctly (cf. Tebrügge and Düring, 1999). The overall impact of scenarios with regards to soil erosion protection, flood and drought risk regulation, and ecological integrity are in agreement with the findings from studies, such as those examining the soil erosion impacts of large-scale cultivation of corn (Luick et al., 2011) or strategic afforestation (Richert et al., 2011).

The minimal impacts seen on returns from land-based production in this study do not appear to be plausible. In the context of our evaluation approach, this may be explained by the fact that the land uses of viticulture and orchards deliver higher contribution margins than the crop rotation classes and that changes of crop rotations therefore do not substantially impact the final assessment results. The estimation of returns from land-based production was particularly difficult, since we were unable to include information on the actual use of agricultural or silvicultural biomass (e.g. for biogas production, construction purposes, etc.), upon which returns are very dependent. For a more realistic estimation, elaborated analyses of value chains (subsidies, market prices, costs, statistical data, etc.) would be necessary. In contrast to the other exemplary scenarios, scenario A-3 had only negligible impacts on ecosystem services provision, although the extensification/afforestation of discharge paths with high concentration of runoff is expected to increase soil erosion protection considerably while changing relatively little area (LfULG, 2008). Here, the negative impacts of being unable to consider neighborhood effects and spatial characteristics on soil erosion protection became apparent (cf. 4.2). Using the curve number as an indicator, the assessment of flood regulation is only sensitive to change of tillage practices, and we were unable to differentiate between crop rotations classes (cf. M-2). Thus, these examples indicate that the application of a single indicator might fall short and that an adaptation of the assessment basis may be necessary.

Our scenario layers are a means for LUC scenario development, since regional planners already arrived at a consensus regarding the designation of such priority areas, which provides a good basis for discussing the implementation of measures with stakeholders (Fürst et al., 2011). The high spatial resolution enabled the identification of management units within the agricultural area. A problem occurred while developing LMC scenarios based on sites sensitive to erosion. The application of e.g. conservation tillage to the affected cells, would have led to different management in one management unit (field block), and thus represented an unrealistic scattering of land management practices. For running plausible LMC scenarios, the given land use data set makes it necessary to consider cells as simulation units as well as field blocks as decision making units. Within the current framework, an approach for the translation of non-spatial scenario formulations into spatially explicit allocation of

LUC/LMC is lacking. Nevertheless, layers showing hot-spots of environmental risks can be a valuable reference as they show which areas are of greatest concern with respect to LUC or LMC.

In order to improve regulating services within our study area, the findings of this study indicate that the best results can be achieved through a combination of large-scale conservation tillage with afforestation of sensitive areas. According to our results, afforestation would be a suitable means to improve flood and drought regulation, soil erosion protection, and also ecological integrity. The latter would be additionally enhanced through better connected forest areas and reduced landscape fragmentation.

4.2 Evaluation of Methodology and Databases

4.2.1 Assessment approach

Information for many indicators which are potentially well suited to assess ecosystem services is very context specific, and therefore difficult to generalize for landscape level assessments (Galic et al., 2012). Therefore, we applied widely used and well known indicators (e.g. yield, C-factor, curve number, SHDI) and concepts (e.g. hemeroby), which we obtained from observed/measured, calculated, or modeled data reported on in the literature or look-up tables (Plummer, 2009; Troy and Wilson, 2006). Nevertheless, we acknowledge that our assessment results are in accordance with the authors perceptions and understandings of ecosystem functioning which has been previously discussed in Koschke et al. (2012).

When the land use/ land management scenarios affected only a few cells, the impact on final evaluation results and the differences compared to the initial situation were low (cf. scenarios E-1 to E-3 and A-1 to A-8 in Figure B.1). Due to the lack of spatial parameters used in our basic approach, we included land use pattern analysis in order to consider ecological integrity. This additional information led to plausible results regarding factors such as the importance of habitat connectivity and diversity of land uses for ecological integrity, and for fostering the integration of these indicators for detailed spatial data sets (cf. Frank et al., 2012). Differences in the provision of ecosystem services caused by site-specific conditions were not accounted for in this case study. This should be addressed in future research, since the location of change may be highly relevant for the performance of certain ecosystem services (Bryan and Crossman, 2008; Rounsevell et al., 2012).

To model the effect of LCC/LUC on selected ecosystem services based on spatially heterogeneous input parameters and environmental drivers, ecological process models can be used (Rokityanskiy et al., 2007; Smith et al., 2005; Nelson et al., 2009). However, for many applications, the use of process models may be impractical due to their complexity, data demand, and scale of assessment (Nelson and Daily, 2010; Nelson et al., 2009; Galic et al., 2012). The application of bookkeeping models or qualitative benefit-transfer based assessment tools such as that presented in this study may be more user-friendly and transparent (Schulp et al., 2008; Busch et al., 2012). Therefore, these tools may be more beneficial to use in cases where trends should be identified in a prior step of in-depth analyses. Also, they may be favorable for analyzing trade-offs in ecosystem services, because process models most often consider one or few ecosystems/ecosystem services in specific accounting units (Busch et al., 2012). Our qualitative approach can be applied at scales relevant to policy making and strategic regional planning, and is able to make best use of available heterogeneous data (cf. Burkhard et al., 2009; Larondelle and Haase, 2012; Busch et al., 2012). Moreover, it is easily transferable to other regions and data sets and does not require laborious parameterization.

4.2.2 Databases

Our EuroMap Land Cover (EMLC) data set comprises aggregated census data on observed crop area share, thus augmenting the thematic content of the data set which is not possible with remotely sensed data alone. Hence, the data set provides an example how information beyond land use/ land cover can be included for ecosystem services assessment if they are available (cf. Rounsevell et al., 2012).

In comparison to previous approaches where we have used CORINE land cover data, the EMLC and crop rotation classes could be well underpinned with average values of regional observed and measured empirical data for some indicators (e.g. yield, C-Factor). This led to greater accuracy of results by reducing the extent of assumptions on the current contribution of crop types and because general purpose data sets such as CORINE tend to overestimate arable land use in comparison to detailed data sets (Schmit et al., 2006; Kandziora et al., submitted). Yet, the selection of relevant indicators to assess other services (e.g. drought risk regulation, flood regulation, returns from land-based production) may remain a perpetual challenge irrespective of the spatial or thematic resolution of spatial data. The effects of crop rotation and tillage changes can be assessed, which is important to highlight the impact of management options, for instance to inform and train non-experts in participation processes. Whereas monitoring of ecosystem services over time would involve time-consuming and costly updates.

By including management practices into land-use classification systems, the multiple impacts of such alternative practices (*e.g.* using conservation tillage as an alternative strategy for flood protection) can both be modeled and assessed within a broader environmental context. This should help raise awareness regarding the consequences of different potential land-uses, and inform the decision making process. The same consideration applies regarding the design of crop rotations, with respect to the implementation of different crop rotation classes and their potential environmental impacts. However, data support at the farm level is often not available, such as the location and timing or fertilizer or pesticide application, which makes the inclusion of such practices difficult in a classification and modeling context. An important consideration regarding the inclusion of more detailed land-use classification system is that it will tend to add uncertainty to the interpretation of results (e.g. model output). Given that the data set created in such a classification system is based on multiple different data sources and resolutions, it will not ever accurately represent one precise point in time. Therefore the value of adding more land use/management alternatives (*e.g.* in this case 85) in terms of providing more information to the stakeholder/decision maker, need to be weighed against the additional uncertainty which will be added as well (cf. e.g. Nerella and Baht, 2004).

Our classification approach yielded valuable information for decision makers for optimizing trade-offs between various ecosystem services under different land use and land management regimes. Because the combined effects of LUC and LMC can be represented at the landscape scale, the detailed spatial data developed in this study provides a better foundation for ecosystem services assessment and mapping than an ecosystem services map derived from land use/ land cover alone. The resulting land use classification is more realistic, and thus more stakeholder-oriented, as it enables the simulation of a wide range of interdisciplinary and realistic scenarios. This according to stakeholder feedback, results in a greater acceptance of the assessment and modeling approach (see also Swetnam et al., 2011). In addition to generic LUC scenarios, the consequences of agricultural policy scenarios can be simulated as well. Since both strategic decision making issues and land-management related questions can be considered in this approach, stakeholders operating at different scales can more easily coordinate, which supports better communication and more effective implementation of conservation or adapted management strategies. Intensive tests with stakeholders will help to examine the actual applicability of the approach in landscape planning practice. For transfer into other regions, standardized land use and land management classification data will have to be defined.

Results of the uncertainty analysis can be helpful to assess the robustness of LUC/LMC measures, which sometimes have unclear impacts and widely varying land use specific indicator values. As any absolute validation of results is inherently impossible in this type of landscape scale study, a comparison of outcomes from studies with similar approaches and/or against process modeling results might be highly valuable to investigate the impact of output uncertainty and error in greater detail.

5 Conclusion

The outcomes of our assessment and investigated scenarios indicate that less intensive land use practices can lead to positive synergies with respect to regulating and supporting ecosystem services (i.e. soil erosion protection, flood regulation, drought risk regulation, and ecological integrity) which is in agreement with the findings of Nelson et al. (2009). Based on the synergies and trade-offs identified, we have made recommendations to regional planners, such as where to better connect forested areas in order to improve flood regulation, erosion protection, and ecological integrity. To reduce soil erosion and to increase flood protection we recommend increasing the spatial diversity of crop rotations, including a higher number of crops per rotation together with conservation tillage. Our findings suggest that efforts aimed at using LUC to meet environmental and/or sustainability goals – mainly afforestation of agricultural sites – should be accompanied by programs that promote beneficial changes in land management practices. A combination of LUC and LMC might be an effective way to sustainably manage ecosystem services at the landscape level.

Land cover/land use data as a proxy for ecosystem services assessment are widely used, whereas land management is often neglected or studied only “from the perspective of farming systems” (van der Steeg et al., 2010). In this study, we have demonstrated that land management can be a major driver for enhancing or reducing the provision of ecosystem services. It should therefore be explicitly considered in similar approaches. Based on previous experiences and feedback of stakeholders, we conclude that high resolution spatial data and the integration of sectoral management information are advantageous in terms of the accuracy of results, the relevance and acceptance for regional decision making, providing information to non-experts, and also for testing more realistic land use options (for example the introduction of linear landscape elements). A certain level of simplification is inevitable to account for the need to reduce complexity, to account for the varying knowledge level of different stakeholder groups typically involved in planning processes, and the fragmented data available regarding land use change impacts. Although there are often ambiguous data on the contribution of land use types to ecosystem services provision, an indicator based approach is suitable to address important issues of sustainable land use planning.

While the meso-scale assessment approach may have higher relevancy for regional policy makers and planners to (re)evaluate or conceive development strategies, it is not suited for farm level decision making support since crop rotation classes can be seen as a compromise between very detailed planning levels and overarching structural planning.

Annex A and B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at: *[to be complemented]*.

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Tables

Table 1 Overview of the selected ecosystem services (and criteria), indicators, methods, and data sources used for the land use-based assessment.

Ecosystem service - Criteria	**Indicator/s**	**Unit**	**Method**	**Data Source**
Food and fodder provision	Agricultural harvest/ yield	dt GEU[a] ha^{-1} a^{-1}	Normalization	Lorenz et al. (subm.), Saxon State Ministry of the Environment and Agriculture (SMUL, 2010)
Provision of biomass	Yield (food, fodder, timber)	kg ha^{-1} a^{-1}	Normalization	Lorenz et al.,(subm.), Saxon State Ministry of the Environment and Agriculture (SMUL, 2010), BMLFUW (2009)
Soil erosion protection	C-Factor (USLE)	-	Normalization	Gebel et al. (2010), Auerswald and Kainz (1998)
Drought risk regulation - Water demand - Water use efficiency	Evapotranspiration Transpiration coefficient	mm ha^{-1} a^{-1} ; l kg^{-1} DM[b]	Multi criteria evaluation and Normalization	Lorenz et al. (subm.), Anders et al. (2002), Geisler (1988), Eibach and Alleweldt (1984), Bernhofer et al. (2011), Roloff (2010), Roth et al. (1998)
Flood regulation	Curve number	-	Normalization	Gebel et al. (2010)
Returns from land-based production	Contribution margin	€ ha^{-1} a^{-1}	Normalization	Saxon State Office for the Environment, Agriculture and Geology (SMUL, 2010; 2012), Bormann et al. (2005)
Ecological integrity[c] - Naturalness - Land use diversity - Landscape fragmentation - Landscape diversity - Habitat connectivity	Hemeroby Number of plant species M_{eff}, CAI; SHDI, PD, SHAPE; CDA	-	Ecological connection matrix (multi-criteria evaluation)	Acc.to Blume and Sukopp (1978)

[a]GEU= grain equivalent unit
[b]DM = dry matter
[c]The overall value of e*cological integrity* is influenced by an analysis of landscape fragmentation, landscape diversity, and habitat connectivity with landscape metrics (LM) (cf. Frank et al., 2012). M_{eff}= Effective mesh size; CAI=Core area index; SHDI=Shannons diversity index; PD=Patch density; SHAPE=Shape index; CDA=Cost Distance Analysis

Table 2 Overview and description of applied land use change (LUC) and land management change (LMC) scenarios. Alternative land use/land management options were therefore: *Management changes* (M) encompassing changes of crop rotation and/or changes of tillage practice (ploughing (P), conservation tillage (CT)); E*xtensification* (E), i.e. change of land use towards permanent grassland (clover=A-1); *Afforestation* (A). ">>" indicates the simulated change, i.e. the applied land use/ land management class.

ID	Label	Description
BAU	Initial	Present (2009/2010) land use and land management (crop rotation, soil tillage (assuming plough on the whole area)) pattern
M-1	Current crop rotation P >> CT	Management (M): Soil tillage practice (P) of present crop rotations change into CT on 100 % of the cultivated area; Because in the study region, almost the whole area was classified highly sensitive to soil erosion >> (CT)
M-2	40 % silage corn (P)	Management (M): Silage corn on 40 % of cultivated area (=42 %) over 10 years (energy crops scenario) + Ploughing >> L10 (P)
M-3	40 % silage corn (CT)	Management (M): Silage corn on 40 % of cultivated area (=42 %) over 10 years (energy crops scenario) + CT >> L10 (CT)
M-4	20 % diversified crop rotations (P)	Diversified but cash-crop oriented crop rotations + Conventional tillage (Plough) >> L4 (P), L6 (P)
M-5	20 % diversified crop rotations (CT)	Diversified but cash-crop oriented crop rotations + CT >> L4 (CT), L6 (CT)
M-6	20 % organic farming crop rotations (P)	Diversified eco-crop rotations (organic farming) + Conventional tillage (Plough) >> L7 (P), L8 (P)
M-7	20 % organic farming crop rotations (CT)	Diversified eco-crop rotations (organic farming) + CT >> L7 (CT), L8 (CT)
E-1	Ext.: Discharge paths (Min.) >> Clover	Extensification (E) only of discharge paths with extreme concentration of runoff (on agricultural sites) >> A1 (P)
E-2	Ext.: Discharge paths (Interm.) >> Clover	Extensification (E) of discharge paths with very high and extreme concentration of runoff >> A1 (P)
E-3	Ext.: Discharge paths (Max) >> Clover	Extensification (E) of discharge paths with high, very high, and extreme concentration of runoff >> A1 (P)
A-1	Affor.: Discharge paths (Min) >> Oak	Afforestation (A) only of discharge paths with extreme concentration of runoff (on agricultural sites) >> Oak mixed…
A-2	Affor.: Discharge paths (Interm.) >> Oak	Afforestation (A) of discharge paths with very high and extreme concentration of runoff >> Oak mixed…
A-3	Affor.: Discharge paths (Max) >> Oak	Afforestation (A) of discharge paths with high, very high, and extreme concentration of runoff >> Oak mixed…
A-4	Affor.: Discharge paths (Min) >> Pine	Afforestation (A) only of discharge paths with extreme concentration of runoff (on agricultural sites) >> Pine mixed…
A-5	Affor.: Discharge paths (Interm.) >> Pine	Afforestation (A) of discharge paths with very high and extreme concentration of runoff >> Pine mixed…
A-6	Affor.: Discharge paths (Max) >> Pine	Afforestation (A) of discharge paths with high, very high, and extreme concentration of runoff >> Pine mixed…
A-7	Affor. of priority areas (Min) >> Oak	Afforestation (A) of priority areas for afforestation (<15ha; Min.) >> Oak mixed…
A-8	Affor. of priority areas (Interm.) >> Oak	Afforestation (A) of priority areas for afforestation (afforestation; Interm.) >> Oak mixed…
A-9	Affor. of priority areas (Max) >> Oak	Afforestation (A) of priority areas for afforestation (nature and landscape; Max.) >> Oak with mixed deciduous tree species

Table 3 Assessed ecosystem services and their normalized indicator values (0-100) on the basis of EuroMap Land Cover (EMLC) classes and incorporated regional crop rotation classes. Crop rotations were evaluated according to two soil management practices, conventional tillage (P=Ploughing) and conservation tillage (CT). (For the complete table, original indicator values, and assumptions see Table A.1 in Annex A)

		Provision of food and fodder 1		Provision of biomass 2		Soil erosion protection 3		Drought risk regulation 4		Flood regulation 5		Returns from land-based production 6		Ecological integrity 7	
1	Very dense urban fabric	0		0		0		0		0		0		0	
2	Dense urban fabric	0		0		0		0		26		0		0	
3	Loose urban fabric	0		0		0		0		51		0		0	
4	Very loose urban fabric	0		0		0		0		77		0		0	
7	Fallow land and ruderal areas	1		1		100		63		95		0		65	
8	Waterbodies	0		0		100		0		100		0		15	
9	Hedges and tree rows	0		11		100		48		100		0		85	
10	Wetlands	0		0		100		0		100		0		100	
11	Viticulture	34		34		67		60		65		100		15	
12	Orchards	55		55		67		46		100		100		15	
13	Hop	89		89		0		40		51		43		15	
20	Urban open space and leisure facilities	0		26		100		30		95		0		15	
21	Grassland (Pastures, meadows)	26		26		100		27		95		10		15	
23	European beech, mixed deciduous forest >20%	0		58		100		88		100		16		65	
27	Oak, mixed deciduous forest >20%	0		58		100		88		100		16		65	
31	Norway spruce, mixed deciduous forest >20%	0		63		100		89		100		18		65	
35	Scots Pine, mixed deciduous forest >20%	0		46		100		60		100		9		65	
43	Softwood, mixed deciduous forest >20%	0		40		100		44		100		11		85	
		P	CT	P	CT	P	CT	P	CT	P	CT	P	CT	P	CT
55	A1 - clover - clover - clover - clover	68	61	68	61	88	99	0	11	50	66	20	19	30	45
56	D1 - w-rape - w-wheat - w-barley	62	55	62	55	78	96	57	65	50	66	43	41	30	45
57	D2 - w-rape - w-wheat - silage corn - s-barley	60	54	60	54	59	95	47	56	50	66	46	44	30	45
58	D3 - w-rape - w-barley - w-rye - grain corn - […]	55	49	55	49	66	96	56	65	50	66	45	42	55	70
59	D4 - w-rape - w-triticale - s-barley - clover - […]	54	48	54	48	76	96	60	69	50	66	41	39	60	85
60	D5 - w-rye - silage corn - s-barley - sunflower	54	49	54	49	54	94	43	52	50	66	49	46	40	55
61	D6 - peas - w-wheat - w-rye - oat	43	39	43	39	76	96	62	70	50	66	41	39	40	55
62	D7 - clover - w-wheat - potatoes - peas - […]	38	34	38	34	65	89	26	36	50	66	71	67	60	75
63	D8 - alfalfa - alfalfa - w-rye - silage corn - […]	39	35	39	35	63	95	30	40	50	66	27	26	55	70
64	D9 - s-barley$_{wps}$ - silage corn - w-triticale$_{wps}$ - […]	53	48	53	48	61	96	57	65	50	66	31	30	40	55
65	D10 - s-triticale$_{wps}$ - sunflower - hemp - w-rye	48	43	48	43	73	93	55	64	50	66	18	17	40	55
66	L1 - w-rape - w-wheat - w-barley	74	67	74	67	83	96	50	58	50	66	43	41	35	50
67	L2 - w-rape - w-wheat - w-barley - w-wheat	70	63	70	63	81	96	51	59	50	66	43	41	35	50
68	L3 - w-rape - w-wheat - silage corn - s-barley	76	68	76	68	64	96	38	48	50	66	46	44	40	55
69	L4 - sugar beet - w-wheat - silage corn - […]	85	77	85	77	70	94	29	38	50	66	48	46	55	70
70	L5 - sugar beet - w-wheat - w-wheat	100	90	100	90	75	94	14	23	50	66	53	50	15	30
71	L6 - peas - w-wheat - w-barley - potatoes - […]	62	56	62	56	78	94	39	48	50	66	67	64	55	70
72	L7 - clover - w-wheat - silage corn - […]	50	45	50	45	64	96	29	38	50	66	43	41	55	70
73	L8 - alfalfa - w-wheat - potatoes - w-rye - […]	51	46	51	46	78	95	29	38	50	66	74	70	60	75
74	L9 - oat - mixed grain$_{wps}$ - w-rape - w-wheat	67	60	67	60	82	96	55	63	50	66	24	23	40	55
75	L10 - silage corn - silage corn - silage corn - […]	78	70	78	70	23	95	0	12	50	66	60	57	15	30
76	V1 - w-rape - w-wheat - w-barley	67	60	67	60	82	96	54	62	50	66	43	41	35	50
77	V2- w-rape - w-wheat - silage corn - s-barley	66	59	66	59	54	96	43	52	50	66	46	44	40	55
78	V3- peas - w-wheat - silage corn - s-barley	53	48	53	48	48	96	44	53	50	66	32	31	40	55
79	V4- w-rape - w-triticale - s-barley - clover - […]	64	58	64	58	78	96	47	55	50	66	26	25	70	85
80	V5 - fieldgrass - silage corn - w-triticale - s-barley	64	58	64	58	50	96	41	49	50	66	19	18	40	55
81	V6 - w-barley - clover - w-rye - silage corn -oat	62	56	62	56	57	96	37	46	50	66	22	21	55	70
82	V7 - clover - w-wheat - peas - w-rape - w-rye - […]	46	41	46	41	71	96	41	50	50	66	30	29	60	75
83	V8 - clover - clover - oat - w-rye - peas - s-barley	47	42	47	42	69	96	34	43	50	66	20	19	55	70
84	V9 - s-barley$_{wps}$ - silage corn - w-triticale$_{wps}$ - […]	55	50	55	50	58	96	55	63	50	66	16	15	40	55
85	V10 - s-barley$_{wps}$ - alfalfa - alfalfa - w-wheat	71	64	71	64	66	96	24	33	50	66	28	27	35	50

(w=winter, s=summer)

Table 4 Mean value points calculated from uncertainty analysis for selected scenarios and respective minimum and maximum value points, and standard deviation (SD) of mean values.

	Food and fodder					Provision of biomass					Soil erosion protection					Drought risk regulation				
	BAU	M-1	M-2	A-3	A-9	BAU	M-1	M-2	A-3	A-9	BAU	M-1	M-2	A-3	A-9	BAU	M-1	M-2	A-3	A-9
Mean	***56***	***51***	***57***	***55***	***40***	***58***	***53***	***59***	***58***	***57***	***78***	***93***	***60***	***79***	***85***	***46***	***51***	***34***	***46***	***57***
Median	*56*	*50*	*57*	*54*	*39*	*58*	*53*	*59*	*57*	*57*	*79*	*93*	*60*	*79*	*85*	*46*	*51*	*32*	*47*	*58*
Min	39	36	39	38	27	42	37	39	41	39	68	92	41	69	79	21	30	17	22	36
Max	75	72	76	73	53	78	73	79	77	80	83	94	72	83	88	67	69	54	67	76
SD	6.7	6.2	7.5	6.5	4.9	6.7	6.4	7.5	6.7	6.8	2.0	0.4	5.8	2.0	1.4	6.9	6.6	7.3	6.8	6.6

	Flood regulation					Returns from land-based production					Ecological integrity				
	BAU	M-1	M-2	A-3	A-9	BAU	M-1	M-2	A-3	A-9	BAU	M-1	M-2	A-3	A-9
Mean	***55***	***38***	***45***	***44***	***38***	***35***	***33***	***40***	***34***	***29***	***32***	***44***	***26***	***33***	***40***
Median	44	38	44	44	38	34	32	39	33	28	31	43	25	32	39
Min	22	20	21	22	17	24	23	27	24	20	23	31	19	24	27
Max	50	47	57	49	52	54	52	64	53	43	42	56	34	42	55
SD	8.6	7.7	9.5	8.4	8.4	5.2	5.0	6.7	5.1	4.3	3.2	4.3	2.3	3.2	4.5

Table 5 Landscape metrics (LM) indicator values, resulting decrement/increment of cell-based value points and LM impact on cell-based values for ecological integrity and selected scenarios. Value points of the criteria (landscape fragmentation, landscape diversity, habitat connectivity) are added up and subtracted from cell-based value points. Value points are derived through combination of indicator performance within ecological connection matrices (adapted according to the approach of Frank et al. (2012).

Scenarios	Core area index (CAI) of natural areas/land use types	Effective Mesh Size (meff) of unfragmented areas	**Landscape fragmentation**	Shannons Diversity Index (SHDI)	Patch Density Index (PD)	SHAPE Inidex of natural areas/land use types	**Landscape diversity**	Cost Distance Analysis (CDA)	**Habitat conncetivity**	**Cumulative decrement/ increment of ecological integrity**	**Cell-based values**	**Values with LM impact**
	[%]	[km^2]	**[Points]**	[-]	[km^2]	[-]	**[Points]**	[%]	**[Points]**	**[Total Points]**	**[Points]**	
BAU	2.1	4.0	**-10**	0.8	0.2	1.4	**-5**	3.0	**-10**	**-25**	**32**	**7**
M-1	2.1	4.0	**-10**	0.9	0.2	1.4	**-5**	3.0	**-10**	**-25**	**44**	**19**
M-2	2.1	4.0	**-10**	0.8	0.2	1.4	**-5**	3.0	**-10**	**-25**	**26**	**1**
A-3	2.1	4.0	**-10**	0.9	0.2	1.4	**-5**	3.0	**-10**	**-25**	**33**	**8**
A-9	26.9	4.3	**0**	1.1	0.1	1.5	**0**	32.3	**10**	**10**	**40**	**50**

Figure Captions

Fig. 1 The REGKLAM region in eastern Germany with the city of Dresden located in the center and the investigated case study area “Großenhainer Pflege” with the current land use/management pattern according to the EMLC data set. The legend depicts common land cover/land use types, forest stand types, and crop rotation classes of the three agricultural regions with predominant diluvial (D) soils, loess (L) soils, and weathered soils (V) soils.

Fig. 2 Flow chart of the approach used to assess the impacts of land use change (LUC) and land management change (LMC) scenarios within this study. LUC and LMC scenarios are assessed by combining (a) values of individual land use/ land management types (cell values) and (b) evaluation of landscape structure (composition and configuration of land use/ land management types).

Fig. 3 Left: Flow charts which show how the scenario layers and policy targets were used to derive LUC and LMC scenarios. Right: Examples for priority areas for afforestation (a; maximum scenario), discharge paths (b; with high concentration of runoff), and areas with high potential erosion risk (c; high and very high) representing areas foreseen for LUC/LMC (grey patches).

Fig. 4 Land use/ land management patterns and assessment results for selected scenarios: M-1, change of conventional tillage practice ploughing (P) of present crop rotations into conservation tillage (CT); M-2, silage corn (P) on 40 % of cultivated area over a 10 year period; A-3, afforestation of discharge paths with Oak mixed deciduous forest; A-9, afforestation of priority areas for afforestation (Max.). Resulting spider charts display scenario results (black line) and results of the initial pattern (BAU, dotted line). The different colors in the maps represent the individual land use classes (cf. Fig. 1).

Fig. 5 Boxplots of normalized landscape level values of selected scenarios as results of the uncertainty analysis. We assumed a 30 % general error of land use/management specific indicator values. Boxplots depict the minimum and maximum values (whiskers), the upper and lower quartiles (box), the median (horizontal line in the box), and the outliers (circles) after 1000 iterations.

Figure 1

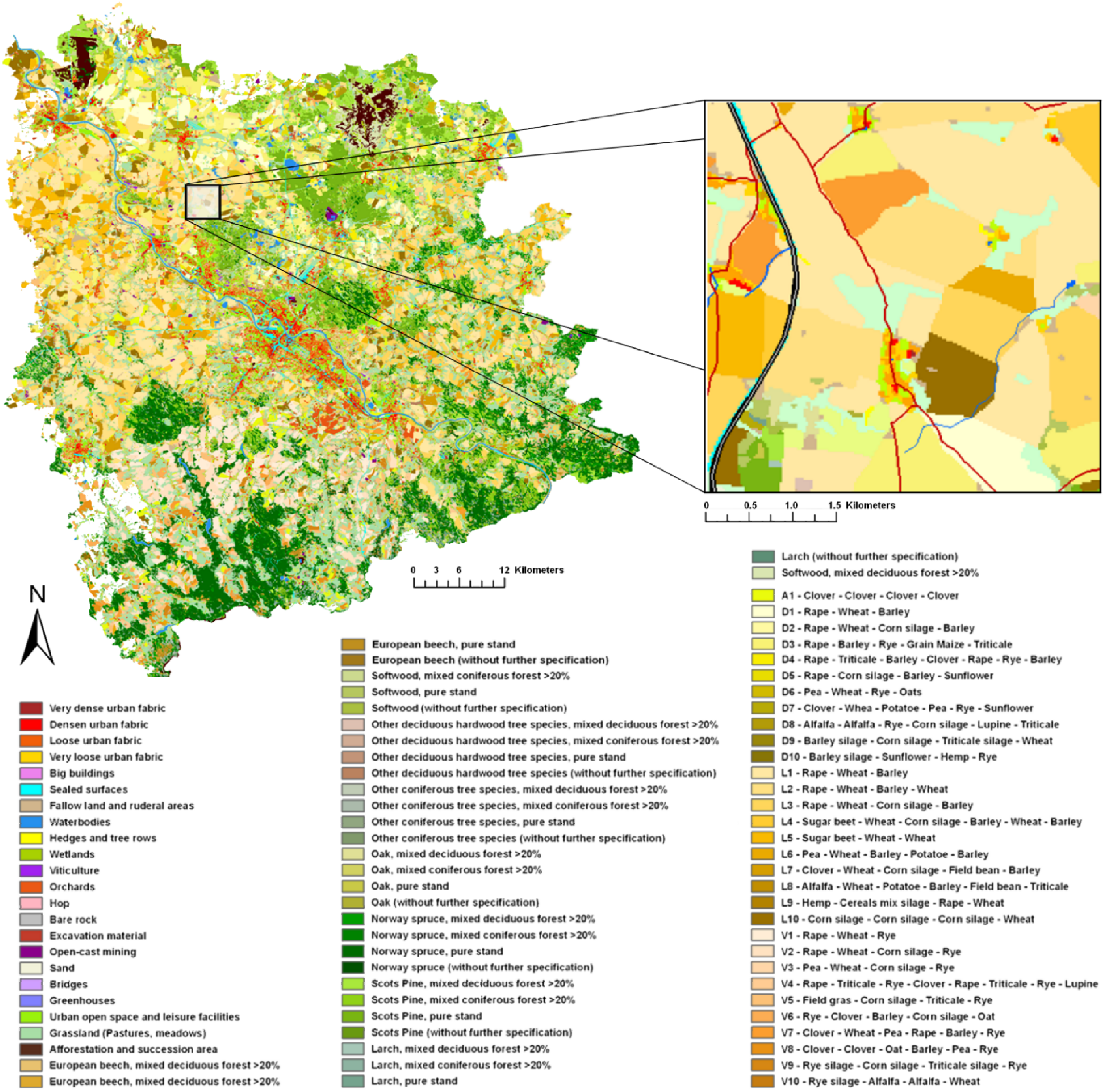

0 0.5 1.0 1.5 Kilometers
0 3 6 12 Kilometers
N
Very dense urban fabric
Densen urban fabric
Loose urban fabric
Very loose urban fabric
Big buildings
Sealed surfaces
Fallow land and ruderal areas
Waterbodies
Hedges and tree rows
Wetlands
Viticulture
Orchards
Hop
Bare rock
Excavation material
Open-cast mining
Sand
Bridges
Greenhouses
Urban open space and leisure facilities
Grassland (Pastures, meadows)
Afforestation and succession area
European beech, mixed deciduous forest >20%
European beech, mixed deciduous forest >20%
European beech, pure stand
European beech (without further specification)
Softwood, mixed coniferous forest >20%
Softwood, pure stand
Softwood (without further specification)
Other deciduous hardwood tree species, mixed deciduous forest >20%
Other deciduous hardwood tree species, mixed coniferous forest >20%
Other deciduous hardwood tree species, pure stand
Other deciduous hardwood tree species (without further specification)
Other coniferous tree species, mixed deciduous forest >20%
Other coniferous tree species, mixed coniferous forest >20%
Other coniferous tree species, pure stand
Other coniferous tree species (without further specification)
Oak, mixed deciduous forest >20%
Oak, mixed coniferous forest >20%
Oak, pure stand
Oak (without further specification)
Norway spruce, mixed deciduous forest >20%
Norway spruce, mixed coniferous forest >20%
Norway spruce, pure stand
Norway spruce (without further specification)
Scots Pine, mixed deciduous forest >20%
Scots Pine, mixed coniferous forest >20%
Scots Pine, pure stand
Scots Pine (without further specification)
Larch, mixed deciduous forest >20%
Larch, mixed coniferous forest >20%
Larch, pure stand
Larch (without further specification)
Softwood, mixed deciduous forest >20%
A1 - Clover - Clover - Clover - Clover
D1 - Rape - Wheat - Barley
D2 - Rape - Wheat - Corn silage - Barley
D3 - Rape - Barley - Rye - Grain Maize - Triticale
D4 - Rape - Triticale - Barley - Clover - Rape - Rye - Barley
D5 - Rape - Corn silage - Barley - Sunflower
D6 - Pea - Wheat - Rye - Oats
D7 - Clover - Whea - Potatoe - Pea - Rye - Sunflower
D8 - Alfalfa - Alfalfa - Rye - Corn silage - Lupine - Triticale
D9 - Barley silage - Corn silage - Triticale silage - Wheat
D10 - Barley silage - Sunflower - Hemp - Rye
L1 - Rape - Wheat - Barley
L2 - Rape - Wheat - Barley - Wheat
L3 - Rape - Wheat - Corn silage - Barley
L4 - Sugar beet - Wheat - Corn silage - Barley - Wheat - Barley
L5 - Sugar beet - Wheat - Wheat
L6 - Pea - Wheat - Barley - Potatoe - Barley
L7 - Clover - Wheat - Corn silage - Field bean - Barley
L8 - Alfalfa - Wheat - Potatoe - Barley - Field bean - Triticale
L9 - Hemp - Cereals mix silage - Rape - Wheat
L10 - Corn silage - Corn silage - Corn silage - Wheat
V1 - Rape - Wheat - Rye
V2 - Rape - Wheat - Corn silage - Rye
V3 - Pea - Wheat - Corn silage - Rye
V4 - Rape - Triticale - Rye - Clover - Rape - Triticale - Rye - Lupine
V5 - Field gras - Corn silage - Triticale - Rye
V6 - Rye - Clover - Barley - Corn silage - Oat
V7 - Clover - Wheat - Pea - Rape - Barley - Rye
V8 - Clover - Clover - Oat - Barley - Pea - Rye
V9 - Rye silage - Corn silage - Triticale silage - Rye
V10 - Rye silage - Alfalfa - Alfalfa - Wheat

Figure 2

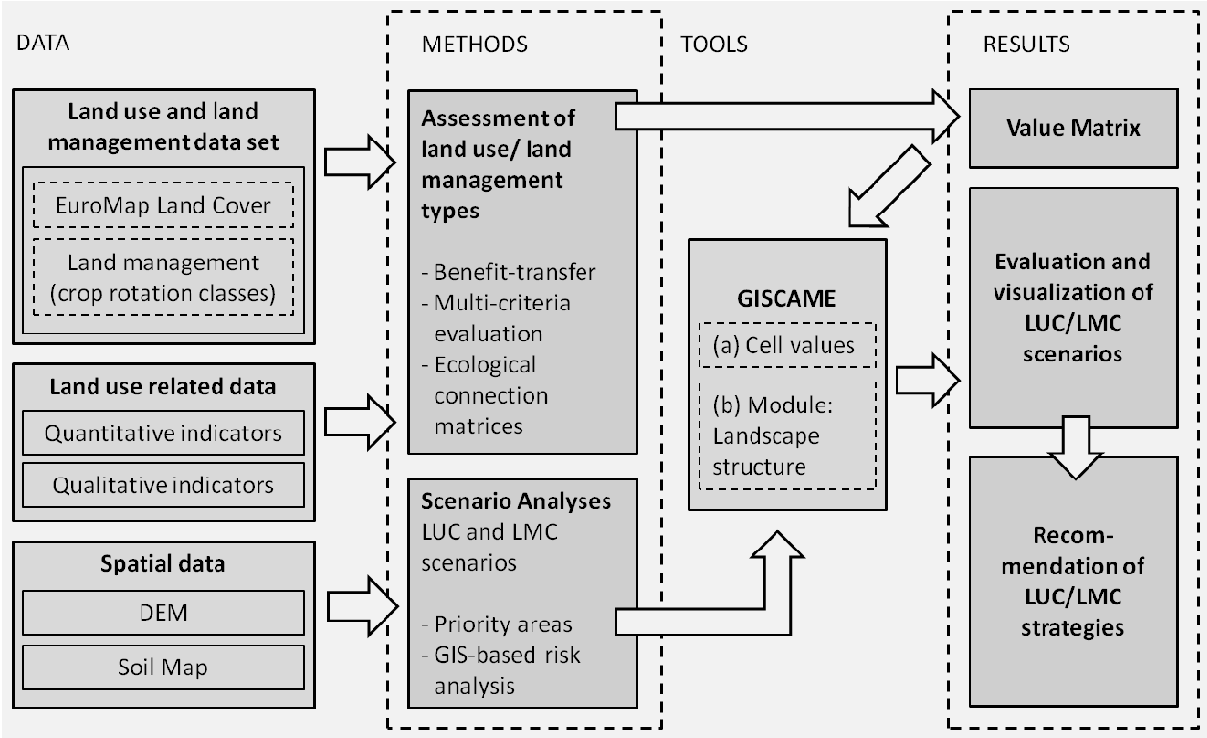


Figure 3

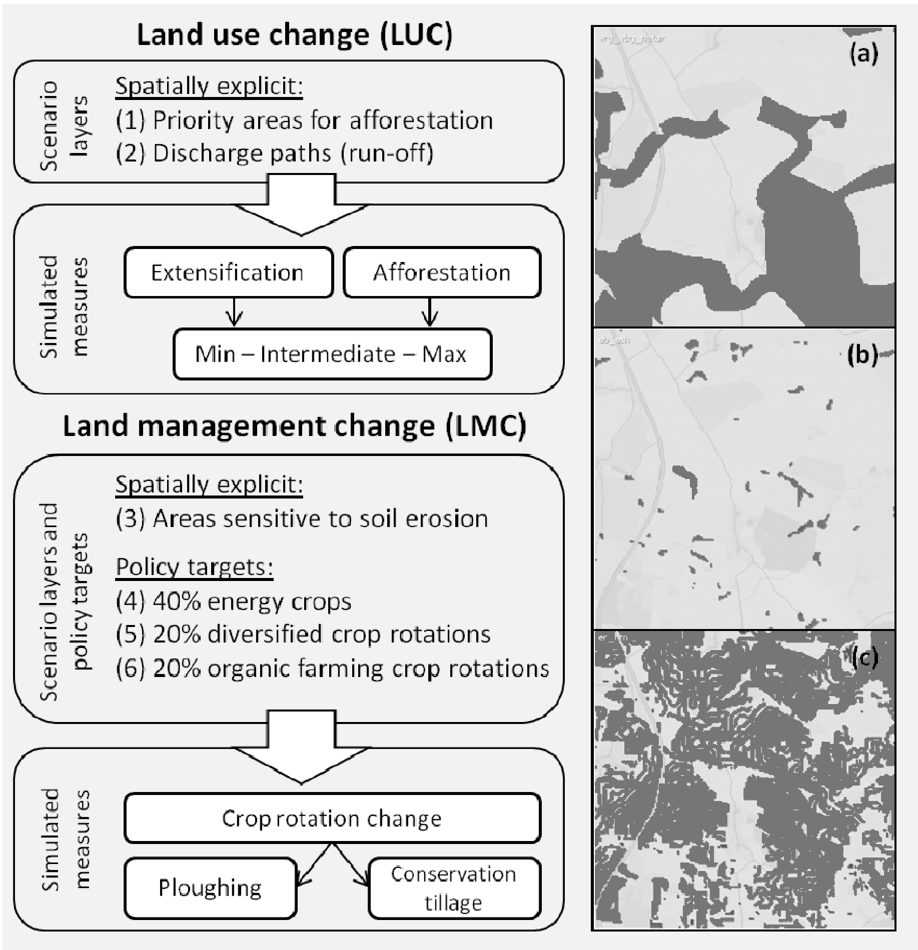


Figure 5

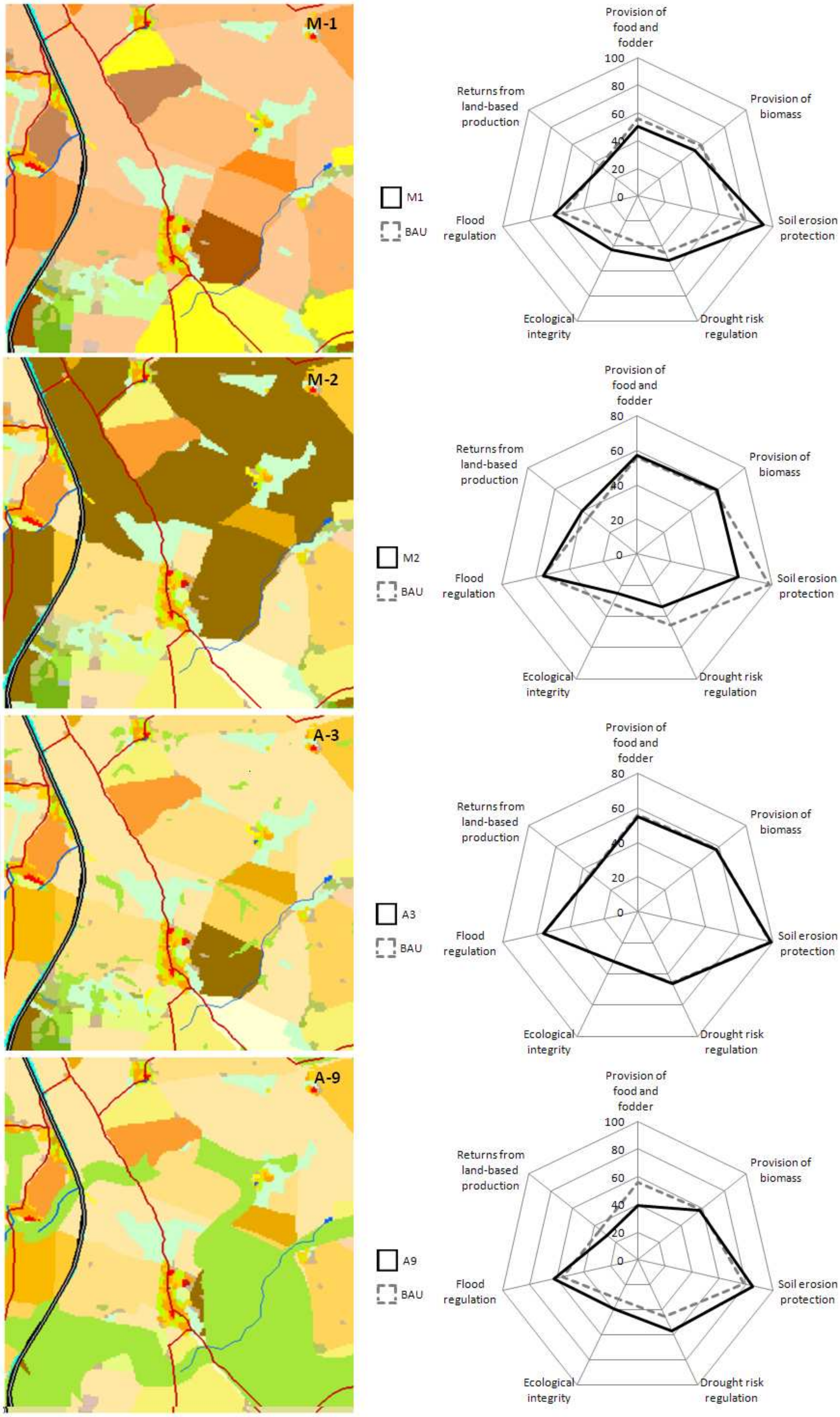
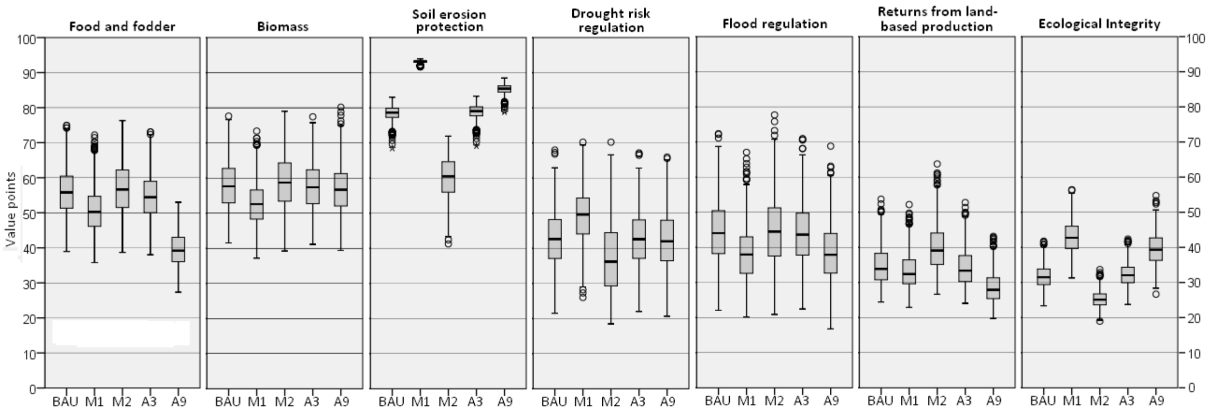

M-1
Provision of food and fodder
Provision of biomass
Soil erosion protection
Drought risk regulation
Ecological integrity
Flood regulation
Returns from land-based production
100
80
60
40
20
0
M1
BAU
M-2
Provision of food and fodder
Provision of biomass
Soil erosion protection
Drought risk regulation
Ecological integrity
Flood regulation
Returns from land-based production
80
60
40
20
0
M2
BAU
A-3
Provision of food and fodder
Provision of biomass
Soil erosion protection
Drought risk regulation
Ecological integrity
Flood regulation
Returns from land-based production
80
60
40
20
0
A3
BAU
A-9
Provision of food and fodder
Provision of biomass
Soil erosion protection
Drought risk regulation
Ecological integrity
Flood regulation
Returns from land-based production
100
80
60
40
20
0
A9
BAU

Figure 5


Food and fodder
Biomass
Soil erosion protection
Drought risk regulation
Flood regulation
Returns from land-based production
Ecological Integrity
Value points
0
10
20
30
40
50
60
70
80
90
100
BAU M1 M2 A3 A9