Ecosystem services modeling in contrasting landscapes

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Abstract Landscape ecology can make a large contribution to ecosystem service (ES) studies since most ESs are place-based, and thus best evaluated, maintained, enhanced, and restored using integrative techniques at the landscape scale. Integration of field observation, modeling, and remote sensing are increasingly used to quantify and assess ES at different scales. In this special issue, several comprehensive methodologies and tools are described in the thirteen papers included. The papers are grouped into four categories: modelling and evaluation of carbon and water services of ecosystems, comprehensive analysis and assessment of multiple ESs, integrated ES methodologies for conservation, and development of integrated modeling environments for ESs. We believe that these papers provide both useful methods and tools to simulate and evaluate ESs at different

spatial and temporal scales, as well as interesting results from case studies. We also hope that they can provide information for policy makers and managers regarding wiser landscape management and conservation.

Keywords Landscape ecology · Ecosystem service assessment · Conservation · Trade-off · Adaptation · Climes · LTER

The significance and advancement in ecosystem services modeling

Ecosystems generate a range of goods and services important for human well-being, collectively called ecosystem services (ESs). It has proven difficult to quantitatively estimate these benefits that nature provides to people (Mace et al. 2012). Spatially explicit values of services across landscapes—of central importance also to inform land use and management decisions—are often lacking. Furthermore, climate and land use changes provide the major challenges for the sustainable management of the key ESs and hence sector-specific adaptation measures are needed (Forsius et al. 2013; Fu et al. 2013). These adaptation measures have to be based on the understanding of (i) the likelihood of change, (ii) vulnerability of the specific sectors to the predicted change, (iii) information about trade-off relationships, and (iv)

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knowledge about the local-scale possibilities for adaptation. This necessitates the development of models and maps in order to estimate where ESs are produced, to quantify the changes in ES provision over time, and to describe the production of ESs as a function of patterns of land use, climate and environmental variation. Landscape ecology has thus a large contribution to make to this field of predicting, monitoring and enhancing ESs since most ESs are place-based, and thus best assessed, maintained, enhanced, and restored using a landscape ecological integrative approach (Iverson et al. 2014). A spatially explicit assessment of ESs can also couple biophysical estimates of ES provision to an economic and monetary valuation (Fu et al. 2011; Maes et al. 2011).

The core of a model is the relationships between parameters or indicators (IEEP et al. 2009). Although it is still not clear how indicators of biodiversity, ecosystem properties, and ESs correlate with each other, the conceptual framework to describe their relationships has been widely discussed. One of the most broadly accepted conceptual framework in ES assessment is the so called “cascade” framework, which depicts the flow of production of ESs from biodiversity and ecosystem properties (Haines-Young and Potschin 2010). Various combinations of ecosystem structures and processes that are supported by biodiversity constitute ecological functions. Those functions that can be directly accessed, used, and demanded by human being are regarded as ESs (Maes et al. 2013). An in-depth understanding of the correlations between the indicators of different categories (i.e., biodiversity, ecosystem structures, ecosystem functions, ESs, and drivers) is helpful in selection of both indicators and models in an assessment.

There have been great efforts in developing ES models in the past decades. The main categories of the models are divided into several groups including biophysical models (which consider one or multiple ecosystem processes or functions), biodiversity models, economic models, scenario models, driver force models, and integrated assessment models (IEEP et al. 2009). Any existing model is built based on the understanding of the relationships (or at least some assumptions of these relationships). Due to the limitations in understanding the mechanisms of ecological processes or the relationships between indicators, the current models still have large uncertainties in representing ESs and their changes in space and time (Burkhard et al. 2013). In

addition, the development of each of the models may have different regional and scaling suitability due to specific research or management targets, and therefore, no one model is fit for all purposes. Validation and comparison of the models in contrasting landscapes are necessary for evaluating model applicability and identifying potential flaws of the models. Combination of different models with varied modules/components or development of new modeling environment is inevitable for implementing comprehensive ES assessment.

About this special issue

This special issue seeks to promote the understanding of processes and develop the methodologies with focus on drivers, interactions and trade-offs of key ESs. Developments and applications of advanced mathematical and extrapolation tools for simulating impacts of future climate, land use and deposition scenarios are also documented. The integrative research presented comprises field studies, statistical analyses of long-term and regional data, dynamic modelling, GIS and remote sensing, and ES accounting in Chinese and European landscapes. The impacts of human activities, especially land use change on ESs are highlighted for the Chinese landscapes; whereas, the coupled effects of climate and land use changes are more emphasized for the European landscapes. The thirteen papers are presented in four categories below. Though many of the papers cover more than one of these categories, we present them here in one as a means to highlight what we perceive as their most unique contribution in this special issue.

Modelling and evaluation of carbon and water services of ecosystems

Wu et al. (2015) simulated the dynamics of soil organic carbon (SOC) stocks in the Yangjuangou catchment of the Loess Plateau (China) using remote sensing techniques and the Yasso07 model. Forest and grassland showed a more effective accumulation of SOC than the other land use types in the study area. The assessment of the model performance indicated that the combination of Yasso07 model and remote sensing data could be used for simulating the effect of land use changes on SOC stock at catchment scale in the Loess Plateau.

In a related larger-scale study, Lu et al. (2014) evaluated the effect of ecological restoration on SOC stocks and determined the influences of multiple factors in the Yanhe watershed of the Loess Plateau. Net primary productivity (NPP) was the foremost factor affecting the spatiotemporal variation of SOC. Converting cropland to grassland was the most efficient restoration type in soil carbon sequestration. Land use change influenced the spatial correlation between NPP and SOC by altering both litter quantity and quality. The results also indicated that the overall effect of ecological restoration on soil carbon sequestration was dependent on the main vegetation restoration type and the time of recovery.

Rankinen et al. (2015) studied the influence of agricultural policy and climate change on changes of water quality in two agricultural catchments in Finland in 1975–2012, with main emphasis on suspended sediment and phosphorus loads. A main conclusion of the study was that in areas where soils are not sensitive for erosion and/or with high animal density, increase in dissolved reactive phosphorus may exceed the benefits of reduced particulate phosphorus load. The focus of the agricultural policies should therefore be on dissolved nutrients as they cause eutrophication in receiving waters.

Arvola et al. (2015) studied the nitrogen concentrations in four small boreal rivers with contrasting hydrology and land use in southern Finland. Their study highlights the importance of inter-annual variability in hydrological conditions (i.e., precipitation, discharge and groundwater) to nutrient cycling. Nitrogen fluxes were at maximum 10–20 times higher during high than low discharge summers. The differences were smallest in those catchments with more lakes or groundwater. The results also indicate that N concentrations were clearly correlated with the proportion of agricultural land.

Comprehensive analysis and assessment of multiple ESs

Dunford et al. (2015) explored the impacts of climate and socio-economic change on multiple ESs across Europe by using the CLIMSAVE Integrated Assessment Platform. The results indicate that future ES provision will be significantly impacted by climate and social-economic changes. Adaptation options offer significant opportunities to decrease pressures on ES provision, but some will necessitate tradeoffs

between ESs. The integrated assessment highlights the importance of taking account of the complex interactions between different sectors under varied scenarios in planning adaptation strategies.

Lü et al. (2014) analyzed landscape transition based on contrasting cases from Finland (Vanajavesi basin) and China (Baota District of Yan'an city). A k-means clustering approach was used to generalize the landscape types based on indicators of landscape composition and its change, spatial pattern, population, and income. The paper shows the value of an analysis and management of landscape spatial heterogeneity based on the information from both landscape status and change.

Liu et al. (2014) analyzed the relationships between various environmental factors and vegetation biomass, litterfall, and coverage of the various grassland utilization types (grazing, fencing, and mowing) using data obtained from 23 sites across temperate grasslands (Hulunbuir region, China). The changing trends of vegetation characteristics in correlation with these environmental factors were predicted using a generalized additive model at the landscape scale. The results indicated that fencing and mowing management practices, which could improve vegetation traits and increase grassland carbon sink, should be continued to promote the health of the Hulunbuir grasslands, rather than grazing management practices.

Posch et al. (2014) have used the effects based approach of critical loads to assess the environmental consequences of elevated sulphur (S) and nitrogen (N) deposition in China and Europe. They present a new methodology to define a single critical load function of N and S for forests and other (semi-)natural ecosystems, and this method is used to compute and map critical loads of N and S in the two regions. The exceedance of these critical loads under globally modeled present and selected future N and S depositions is also assessed, and the sensitivity of the critical loads and their exceedances to the choice of the chemical criteria is investigated.

Integrated ES methodologies for conservation

Vihervaara et al. (2015) examined the utility of combining remote sensing-derived forest characteristics with bird species distribution data for ES assessment at landscape scale. The method is evaluated for 41 boreal forest bird species and 14 structural forest parameters in southern Finland. The results show clear distinction

between the biodiversity-ES relationships among different species. The study suggests that the method can be used as a basis for quantifying spatially-explicit biodiversity indicators for ES assessment.

Maes et al. (2014) base their analysis on the concept of Green infrastructures (GI), and assess how current trends of land use change have an impact on the aggregated provision of eight ESs at the regional scale of the European Union, measured by the Total Ecosystem Services Index (TESI8). The paper reports how further implementation of GI across Europe can help maintain ESs at baseline levels. Moreover, the study analyses how current demographic, economic and agricultural trends, which affect land use, are expected to decrease TESI8 across Europe.

Zhang et al. (2015) have measured the trade-offs between multiple ESs in a decision-making process. They map the water supply, soil conservation, and net primary production as ESs in the Jiangxi province of China in the year 2010, and use risk, tradeoff, and spatial efficiency indices to measure the conservation efficiency of seven established ordered weighted averaging (OWA) scenarios under two conservation levels. It is concluded that the use of GIS-based OWA methods can balance conflicts among multiple ESs and can significantly enhance the spatial efficiency of the identified priority areas.

Development of integrated modelling environments for ESs

In order to promote the efficiency of ecosystem planning and management, Hu et al. (2015) have developed a spatial decision support tool named SAORES, which provides a platform for exploratory scenario analysis and optimal planning design. A case study on the Yangou catchment of the Loess Plateau, China is presented, and based on impact assessment of a ‘Grain for Green Project’, farmland retiring planning is optimized involving multiple objectives.

Holmberg et al. (2015) developed a web based research environment named ES Lab for evaluation of ESs at different scales. The open web tool allows researches to present and share the results as visual maps, statistics and graphs. The themes included in the pilot are related to biodiversity conservation, climate mitigation and eutrophication mitigation. Case studies for the pilot application in a boreal region of southern Finland are presented.

Concluding remarks

This collection of papers presents significant work on linking biodiversity indicators and ESs, quantifying trade-offs among multiple ESs, predicting ES changes under varying scenarios (climate, land use, deposition, socioeconomic, and management scenarios), and developing open-accessed modeling environments, representing highly important research advances in present day ES sciences. The papers include relevant case studies in China or Europe, demonstrating that field observations are indispensable for model development and validation. Future efforts in ES assessment should make the most of multiple data sources for modeling needs. Integration of field observations, remote sensing, and modeling has shown the great advantage of data fusion, method complementation, and scale transformation in these studies. Development of a public network platform is particularly important for reduction of model uncertainties and improvement of integrative analysis, as it provides a ground for researchers to share indicators, modules, data, and experiences. It is an important step for methodological standardization of ES assessment, or the so-called “blueprint” for ES indicators, modeling, and mapping (Crossman et al. 2013). This calls for a far-ranging collaboration among model developers, remote sensing and GIS experts, long term ecological research networks (e.g., LTER), managers, and policy makers.

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