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Mapping landscape services, spatial synergies and trade-offs. A case study using variogram models and geostatistical simulations in an agrarian landscape in North-East Germany

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ABSTRACT

This paper presents a probabilistic approach for mapping and assessment of services provided by landscapes, based on variogram modelling and geostatistical simulations. Of operational value is that several services can be treated and mapped simultaneously, providing an efficient tool to model the heterogeneity of different landscape components. The methodology was adopted to depict spatial heterogeneity of five landscape services in the case study area of *Märkische Schweiz* in North East Germany: habitat for species, crop production, visual appreciation, water supply, and water regulation. Results, displayed in terms of single and joint probability maps, provide new insights about the composition and interrelation of multiple services in a region. It is shown that each landscape service is characterised by a specific spatial pattern, described in terms of heterogeneity and spatial range. Setting a probability threshold of service occurrence >0.50, 10% of the area under agricultural land uses provides no landscape services, 35% delivers one service while 25% and 19% supply two and three services, respectively. The share of agricultural area with a potential joint provision of four services equals 10%, while only 1.4% of the area has a potential to deliver five joint landscape services. The highest mean join probability is that observed for the common supply of production and habitat services (30%), highlighting the occurrence of hotspots of services provision with possible conflicts due to the on-going intensification of agricultural management.

1. Introduction

Among the growing stock of research in ecosystem and landscape functions and services (de Groot et al., 2010; TEEB, 2010), factors determining their main spatial characteristics, i.e. variability and extent, are often overlooked. Their consideration requires development of methods and tools to quantify and map different services across the landscape (Anton et al., 2010). In order to support sustainable land use decision-making, the analysis of spatial heterogeneity and patterns of the diverse functions and services across a given landscape should be able to explore and identify interaction effects and potential spatial synergies, i.e. 'multiple win locations' or multifunctional 'hotspots' (Gimona and van der Horst, 2007; Egoh et al., 2008; Wu et al., 2013). The availability of spatially explicit information on the state and trends of these functions and services is crucial to support valuation and to inform landscape policies and decision making (Maes et al., 2012; Syrbe and Walz, 2012).

Although the terms landscape and ecosystem services are often used as synonymous (Lamarque et al., 2011), we prefer to use the former over the latter as processes-pattern relationships are more clearly understood and modelled at landscape scale (Termorshuizen and Opdam, 2009; van Zanten et al., 2013). Furthermore recent studies point out that local stakeholders have a better understanding of the broader concept of "landscape" than "ecosystem" (Fagerholm et al., 2012; Gulickx et al., 2013), as the landscape can be viewed as the spatial context where natural and socio-economic systems intersect (Wu et al., 2013).

There is a growing body of available literature on landscape service mapping which highlights a number of different methodological approaches at different spatial and temporal scales (Baral et al., 2013), including land use/cover based assessments (Burkhard et al., 2012; Haines-Young et al., 2012; Koschke et al., 2012), bio-physically based modelling (Bryan and Crossman, 2013),

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landscape-landform type mapping (Hermann et al., 2014), ecosystem structure mapping (Lavorel et al., 2011; Brown et al., 2013) or dynamic process-based ecosystem models (Kareiva et al., 2011; Bagstad et al., 2013). As effective spatial scales and patterns of landscape services vary, scale dependency must be taken into account to select the proper approach depending of the indicators to map (Gulickx et al., 2013). Some of the existing modelling approaches are more suitable for large scale studies, where services are directly related to land use and are typically qualitative (e.g. Burkhard et al., 2012), while others, such as those based upon modelling outputs, can have application from the plot to the landscape scale (e.g. Bryan and Crossman, 2013). Yet, the application of spatially explicit methods that incorporate the locations of supply and demand of landscape services represents a key challenge for research, and there is the necessity to develop and test different approaches to quantify and (jointly) map different services across the landscape, highlighting "hotspots" with synergies and conflicts. Therefore the objective of this study is to present a flexible and generally applicable probabilistic approach to landscape scale assessment and mapping of different landscape services. We apply the approach in the case study area *Märkische Schweiz* in North-East Germany.

Within this framework, highly adaptable and consistent, landscape elements and services are considered as the realisation of a stochastic process called random function (Chilès and Delfiner, 1999). Their spatial properties can be described and modelled using second order statistics, such as the variogram which describes the spatial relationships between data and models the spatial heterogeneity of the different landscape components. The use of variograms and other geostatistical tools to model and map environmental variables is not new in environmetrics (Jensen et al., 2006) and landscape ecology (Rossi et al., 1992; Maisel and Turner, 1998), and an applications to linear landscape elements mapping at small scale has been recently provided by van der Zanden et al. (2013). Nevertheless, their potential in landscape services provision assessment has not yet been fully tested and assessed. To this aim, objectives of this work are to analyse and model the spatial heterogeneity and patterns of the diverse functions and services across the given landscape, and to explore and identify in probabilistic terms services hotspots and ranges.

2. Material and methods

2.1. Study area

The case study area (576.4 km^2) is located in the Federal State of Brandenburg, extending from the Eastern fringe of Berlin towards the Odra valley at the German-Polish border (Fig. 1a). The landscape morphology was shaped by cyclic glacial advances of terrestrial Scandinavian ice sheets as well as by peri-glacial geomorphologic processes, resulting in heterogeneous natural conditions in terms of geomorphology, pedology and topography (Scholz, 1962), with elevation ranging between 5.8 m and 144 m a.m.s.l. Based on geomorphology, dominant soils and related land cover, the area is subdivided into six major sub-landscapes (Meynen and Schmithüsen, 1962, Fig. 1b): Glacial valleys: (i) *Rotes Luch* (45.0 km^2, 7.8%) and (ii) *Buckow Valley* (92.0 km^2, 15.6%); Ground- and end-moraines plateaux: (iii) *Lebus Plateau* (88.1 km^2, 15.3%), (iv) *Barnim Plateau* (206.6 km^2, 37.8%) and (v) *Oberbarnim* (88.0 km^2, 15.3%); Slope sides; (vi) *River Oder Valley* (45.0 km^2, 7.8%). The soil typologies, with the exceptions in the River Oder Valley and some areas in the ground and loamy terminal moraines, are all characterised by a general low fertility (Fig. 1c). This is assessed based on the German Soil Evaluation System as being between 30 and 60 for arable land and between 30 and 50 for grassland in a scale from 0 to 100 (MLUR, 2000).

Forest areas (39.9% of total area) cover the largest proportion of the plateau and moraines areas (49.0%), while agricultural lands (45.8% of the total area) are dominant in the ground and loamy terminal moraines, representing nearly 73% of these areas (EEA, 2007, Fig. 1a). Due to the disadvantaged natural conditions, nearly all the area (94%) is subject to the less-favoured area scheme (LFA, Council Regulation (EC) No 1698/2005). Additionally, nearly half of the area is designated for nature conservation with NATURA 2000 (Directive 92/43/EEC) and Flora–Fauna–Habitat (Directive 92/43/EEC) areas covering 31% and 9%, respectively, of agricultural land. In total, about 43% of the territory (245 km^2) is designated for nature conservation of various status. The major protection area is the Naturpark *Märkische Schweiz* (205 km^2). Due to its mixture of forest and farmland patches, the case study area appears as half-open countryside with the potential to provide various landscape services, including food and fibre production natural amenities, water resource provision, species habitat and recreation.

2.2. Landscape structures and services

Landscape services are defined as "the goods and services provided by landscape to satisfy human needs, directly or indirectly" (Termorshuizen and Opdam, 2009). Examples of landscape services are food production, pollination, water regulation, and provision of recreation (Gulickx et al., 2013). Valuation of landscape and ecosystem services through stakeholders has been applied in many studies (Hein et al., 2006). Therefore, landscape services subject to this study have been identified and selected by relevance for the region. In January 2013, 13 local stakeholders from administration, regional management, NGOs and agriculture carried out a prioritisation and weighting procedure of landscape services based on inter-linkages with land management on the one side and with the endowment for regional socio-economic welfare and competitiveness on the other. As result, habitat for species (HAB, $N = 22$) and visual appreciation (VIS, $N = 18$) ranked highest, followed by crop production (PRO, $N = 9$) as well as water supply (WAS, $N = 8$) and regulation (WAR, $N = 8$). As far as it concerns the land management, the high-ranked regional identity ($N = 25$) and recreation ($N = 16$) are closely related to visual appreciation and are therefore not considered separately. Table 1 gives an overview of the landscape services, including the proxy indicators and data sources used in this study. The application procedures to infer the potential services supply are described in the following paragraphs.

2.2.1. Habitat for species

The percentage of areas under protection schemes in the agricultural fields and grasslands has been used as proxy of habitat provision for a manifold field flora and fauna, especially birds (Hoffmann, 2006) and flowering plants (Hoffmann, 1993). The threshold was arbitrarily set at share $\geq$30% for any given field. The total percentage of areas under NATURA 2000 is 28% and 63% for agricultural fields and grasslands, respectively, and rises up to 82% for permanent crops (MIL, 2012).

2.2.2. Crop production

The yield potential for field crops in the area ranges from very low to medium (Fig. 1c). Accordingly to the German Soil Evaluation System, seven classes of yield potential are found in the area (*Reichsbodenschätzung*, MLUR, 2000) and mapped at a 1:200,000 scale: the classes <30 (two classes), representing ca. 46% of the area, are under forestry, while the classes >50 (three classes) occupy only about 7% of the area and are those with the most productive agricultural soils. The areas with the intermediate classes with a score between 30 and 50 (two classes, ca. 47% of the area) are under cultivation. Typical crops include winter rye (*Secale cereale*), winter rape (*Brassica napus*), silage mais (*Zea mays*) and winter wheat