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Mapping and analysing historical indicators of ecosystem services in Germany

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ABSTRACT

In recent ecosystem service studies, historical data have gained importance as basis for analysing temporal trends and for adapted land management strategies; however, the total number of such studies remains small. Contributing to recent efforts, the primary objective of this study was to assess local ecosystem service products historically used in Germany and to link their distribution patterns to environmental gradients and traditional land-use systems. From maps and detailed regional descriptions of regionally distinct historic farmsteads, building materials used and village types we extracted information on ecosystem service products appropriated in 1950 and before. A spatial model was used to test the derived ecosystem service diversity against topo-climatic conditions. Regional service richness was further compared to the type of traditional land-use system (i.e. focus on crops, focus on livestock or mixed systems). We were able to identify hot spots of historical ecosystem service provisioning in Northern and Southern Germany, whereas significantly lower service numbers were recorded in Eastern Germany. The strong spatial differences in the diversity of historical service products could be explained best by (high) precipitation during the vegetation period. Furthermore, traditional livestock keeping, which relied on various fodder sources and fertilisation techniques to improve poor soil quality, and mixed systems mostly co-occurred with higher regional ecosystem service richness. The baseline of historical ecosystem service provisioning analysed here aids our understanding of current land-use patterns in Germany. Furthermore, a change of perception for specific landscape elements became apparent from our analyses. For example, hedges planted to separate livestock and to provide fuel in the past are today appreciated as important elements for biodiversity conservation. Furthermore, our study helps to preserve knowledge about locally sourced ecosystem services thereby increasing the understanding of cultural landscapes which may help to maintain their remnants.

1. Introduction

In recent ecosystem service (hereafter ES) studies, historical data have gained increasing importance in determining trade-offs and synergies among multiple ES and as basis for adapting land management strategies (Morán-Ordóñez et al., 2013; Renard

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et al., 2015; Tomscha and Gergel, 2016). However, the total number of such studies remains small (Plieninger et al., 2016) and the published research are either based on public statistics and infrastructure indicators (Renard et al., 2015), land cover maps and historical aerial photography (Lautenbach et al., 2010; Tomscha and Gergel, 2016) or literature and technical reports (Morán-Ordóñez et al., 2013). Despite the variety of methods applied, they commonly conclude that (i) better baseline information on the past provisioning of ES is needed and that (ii) ignoring time will limit the understanding of complex ES dynamics and interactions (e.g. Renard et al., 2015; Tomscha and Gergel, 2016).

The use of historical data may provide insights into the diverse sets of ES that have shaped and maintained agricultural cultural landscapes (Antrop, 2005), which are the outcome of the co-evolution between human society and the environment over time (UNESCO, 2014). Such cultural landscapes are the result of human-induced changes through traditional land-use systems (i.e., practices that are not part of modern, intensive agriculture; Bignal et al., 1995) intended to fulfil societal demands for agro-ecological (ecosystem) products and services (Antrop, 2005; Fisher et al., 2009). Traditional cultural landscapes, found across the globe, contribute to aesthetic qualities (Hartel et al., 2014) and foster genetic, organismal and ecological diversity (e.g. Heath and Tucker, 1995; Herzog, 1998). Furthermore, such landscapes preserve regional agricultural knowledge and the diversification of management systems which provide a buffer against unforeseen stochastic events or disturbances, thereby increasing landscape resilience (Barthel et al., 2013).

Multifunctional cultural landscapes are valued for their ecological, social and historic functions (Barthel et al., 2013; Plieninger et al., 2013), yet they are vulnerable to the twin threats of agricultural intensification and abandonment due to their low economic returns and changing perceptions of their value (Hanspach et al., 2014). Both abandonment and intensification have led to a loss of numerous provisioning ES and the related agro-biodiversity worldwide (von Wehrden et al., 2014) and fundamentally altered traditional cultural landscapes. In order to establish strategies to maintain and protect cultural landscapes and their related agro-biodiversity, a better understanding on how such landscapes developed as a result of their environmental conditions and anthropogenic use is needed (Farina, 2000; Morán-Ordóñez et al., 2013).

Compiling data on historical provisioning of ES in cultural landscapes as a starting point for detailed (temporal) analyses poses challenges, mainly due to the fact that historical data cannot be directly collected but has to be derived from existing data sources. In particular, spatially explicit data on the provisioning of ES are hard to come by. Historical aerial photography is probably most promising (e.g. Lautenbach et al., 2010; Tomscha and Gergel, 2016) in this context but also restricted by data availability when working across broad spatial scales or over long periods of time. Therefore, there is a need to find proxy indicators that can capture historic ES provision and to relate those services to cultural land forms and environmental conditions.

In this study, we apply the ES concept to a dataset on the distribution of historical farmhouses, construction materials used, village and farm types throughout Germany in 1950 and before (Ellenberg, 1990). We extracted information on ES products, which are defined as the goods and benefits derived from ES (Haines-Young and Potschin, 2013). While we identify and investigate some of the interdependencies of ecological and human systems that shape cultural landscapes, our study has two main aims: first, we analyse whether different traditional land-use systems can be related to differences in regional ES richness; second, we explore if the spatial distribution of service diversity can be explained by environmental conditions such as precipitation, temperature and terrain ruggedness.

2. Data and methods

2.1. Study area

Germany is characterized by large topo-climatic gradients (altitude: −3–2962 m a.s.l., mean annual precipitation: 483–2340 mm, mean annual temperature: −3.7 – 11 °C, mean annual sunshine duration: 1376–1873 h) which can be related to the various forms of cultural landscapes and rural construction methods found (Ellenberg, 1990). Traditional land-use systems in Germany until approx. 1800 mainly aimed at the continuous supply of multiple products, rather than on optimizing yield (Beck, 1986). While land close to villages was mainly used for crop production, grasslands and more distant forests were used for livestock keeping (Schulze-Hagen, 2004). While the change from natural to rural landscapes was gradual, two major periods of land-use change have been described (e.g. Antrop, 2005; Haase et al., 2007). Within the first period (19th century until the Second World War, Fig. A1), common land was increasingly privatized and used for crop production, chemical fertilizers were first introduced, mechanization of agricultural production began and livestock housing systems became more popular. The second period of land-use change (post-World War landscapes) can be characterized by (1) the intensive use of chemical fertilizers and plant protection products (Spielman and Pandya-Lorch, 2009), (2) land consolidation (Bičík et al., 2001), the exchange of small and scattered agricultural areas between different farmers in order to form larger, continuous fields with a single owner (FAO, 2015), (3) further mechanisation and specialisation of agricultural systems and (4) industrial livestock keeping with intensive grassland management (Schulze-Hagen, 2004). Overall, competitive advantages due to environmental conditions, economies of scale in production and the use of external inputs to bolster production led to increased land-use specialization and landscape homogenization (Blaxter and Robertson, 1995). Both periods of change have fundamentally transformed cultural landscapes in Germany and led to a degradation of many ES and a severe loss of biodiversity (e.g. Poschlod et al., 2005).

2.2. Overview of data sources and methods applied

Within the study at hand, we used different data sources and methods to answer our two main questions (Fig. 1). Further details on each of the steps are described in the following (see section *Maps* and *Regional descriptions* for more information about the data recorded by Ellenberg; see section *Spatial regression of historic ecosystem service diversity and environmental variables* for environmental variables analysed).

2.2.1. Historical information about rural landscapes in Germany

Heinz Ellenberg (1913–1997) was a German botanist, who mainly conducted research in the field of vegetation ecology and developed a 9-point scale in order to rate the preferences of plants for environmental factors (Leuschner, 1997). Beside this work, he was also interested in the temporal evolution of housing types in traditional cultural landscapes. This interest resulted in the publication of his book “Bauernhaus und Landschaft” (“Farmhouse and Landscape”, 1990). By compiling maps, notes and photographs, Ellenberg collected this rich and unique source of data about historical building types, construction materials, farm types, village forms, and landscape elements and their spatial distribution in Germany. He gathered data between 1932 and 1988 and explicitly stated that his aim was to provide historical information about the rural landscapes in 1950 and before throughout Germany. We