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Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape

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HIGHLIGHTS

- Identification of potential synergies for increasing multifunctionality.
- Distinct differentiation in the distribution and groupings of ecosystem services in Denmark.
- Cultural and regulating services segregated from provisioning services in cultural landscapes.
- Ecosystem service bundle types highlighting the spatial trade-offs and synergies.
- Coastal areas important for cultural services.

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ABSTRACT

We made a spatial analysis of 11 ecosystem services at a 10 km × 10 km grid scale covering most of Denmark. Our objective was to describe their spatial distribution and interactions and also to analyze whether they formed specific bundle types on a regional scale in the Danish cultural landscape. We found clustered distribution patterns of ecosystem services across the country. There was a significant tendency for trade-offs between on the one hand cultural and regulating services and on the other provisioning services, and we also found the potential of regulating and cultural services to form synergies. We identified six distinct ecosystem service bundle types, indicating multiple interactions at a landscape level. The bundle types showed specialized areas of agricultural production, high provision of cultural services at the coasts, multifunctional mixed-use bundle types around urban areas and forest recreation bundle types with high hunting potential. Thus we found that the distributions were both determined by historical and current socio-ecological influences. This gives a better understanding of the interactions between multiple services in the landscape and the way the landscape has been managed. However, the number, types and spatial distribution of such bundles are quite sensitive to the individual ecosystem services selected and the input data available to define these services. This should be taken into consideration in further research on how to utilize the existing synergies and the mitigating potential of trade-offs for a more holistic approach to landscape-scale ecosystem service management.

1. Introduction

Ecosystem services are the goods and services that ecosystems provide to society and may be categorized as provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment [MA], 2005). Wherever humans live, complex socio-ecological interactions are formed with the surrounding landscape, affecting the availability and usage of ecosystem services. For example, social drivers such as urbanization, agriculture and associated deforestation influence the distribution of ecosystems and their services (Alberti, 2005; Geist & Lambin, 2002; Power, 2010). These

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different uses of the landscape are termed spatial trade-offs or synergies, depending on whether the presence of one service excludes the presence of another service or multiple services are able to coexist in the same area (Rodriguez et al., 2006). Trade-offs between for instance agroecosystems and wetlands and their associated services may cause one service, e.g., provisioning of agricultural products, to damage other services, for example via drinking water pollution, lake eutrophication, or habitat loss (Carpenter et al., 2009; Pretty, 2008). There can also be positive interactions – synergies – between multiple services, such as wild flower patches in agricultural land that increase pollination and yield of crops (Bennett, Peterson, & Gordon, 2009; Raudsepp-Hearne, Peterson, & Bennett, 2010). Consideration of such positive and negative interactions between ecosystem services is thus crucial for landscape planning to avoid costly negative trade-offs and promote multifunctionality (Bennett et al., 2009).

Spatial trade-offs and synergies between ecosystem services may cause multiple services to form so-called spatial bundles because of their connectedness or interdependence across a given landscape (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). Importantly, quantification of spatial bundles enables geographic representation and analyses of related ecosystem services without the double-counting that would result if they were treated as unrelated entities (Raudsepp-Hearne et al., 2010; Rodriguez et al., 2006). Such analyses have revealed that the landscape distribution of ecosystem services may correspond to predictable socio-ecological subsystems and associated land-use types, e.g. agriculture, forest recreation, and multifunctional land uses (Dick et al., 2010; Raudsepp-Hearne et al., 2010). Importantly, spatial bundle analyses may capture how naturally occurring ecosystem services are linked with human-controlled land uses and their directly associated services (Bai, Zhuang, Ouyang, Zheng, & Jiang, 2011; Dick et al., 2010; Raudsepp-Hearne et al., 2010).

Currently – and even more so in the future – many landscapes will be intensively managed and dominated by strong agricultural and urbanization pressures (Borgström, Elmqvist, Angelstam, & Alfsen-Norodom, 2006; Laterra, Orúe, & Booman, 2012; Raudsepp-Hearne et al., 2010; Uthes et al., 2011). Here, ecosystem services are produced under high human population densities and farming intensity (Carpenter et al., 2009; Ellis, Goldewijk, Siebert, Lightman, & Ramankutty, 2010; MA, 2005). Understanding trade-offs and synergies among ecosystem services in such landscapes dominated by humans are therefore crucial. In the present study we address this issue for Denmark, a densely populated and intensely farmed region (Dalgaard et al., 2007). Our specific study questions were: (1) Are there distinct spatial patterns of ecosystem services across Denmark? (2) Are there specific spatial trade-offs and synergies between ecosystem services? (3) Do multiple ecosystem services consistently coexist and form spatial ecosystem bundles? To answer these questions we used the framework developed by Raudsepp-Hearne et al. (2010) for a Canadian peri-urban agricultural landscape, allowing us to compare the findings of the two studies. This will in the following simply be referred to as the Canadian study.

Following the Canadian study, some ecosystem services were represented by land use or land cover data. There has been much debate on the accuracy and use of coarse-scale regional studies with simple land use or land cover data for estimating ecosystem services, as is used with this framework (Bennett et al., 2009; Burkhard, Kroll, Müller, & Windhorst, 2009; Seppelt, Dormann, Eppink, Lautenbach, & Schmidt, 2011). Certain ecosystem services such as agricultural provisioning services are in fact closely tied to specific land uses and associated land covers. As in our case, an important additional reason for choosing land use/land cover data is that this type of information is broadly available and enables data comparison between regions (Raudsepp-Hearne et al., 2010). Alternative complex landscape-scale assessments of multiple ecosystem services are often difficult to apply to different landscapes, limiting our ability to compare and generalize (Koschke, Fürst, Frank, & Makeschin, 2012).

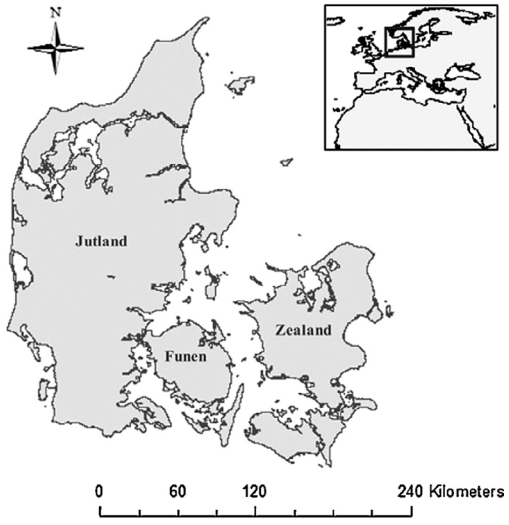

Fig. 1. Denmark.

2. Materials and methods

2.1. Study area

Our study area was the land area of Denmark (43,000 km^2, Fig. 1), excluding the islands of Bornholm, Ertholmene, Læsø, and Anholt. Ertholmene (two islands) were considered too isolated (>100 km from the mainland) to be geographically coherent with the rest of Denmark; the latter two were excluded because of missing data. This resulted in a final study area of 41,965 km^2.

The Danish landscape has been formed by erosion and sedimentation from the glacial cover of northern Europe, which is manifest in its low rolling hills and flat glacial deltas (Meesenburg, 1996). It consists of the peninsula Jutland, the two major islands Funen and Zealand and another 407 smaller islands, giving Denmark a long coastline of approximately 7300 km and a distinct physical boundary for the analysis. The climate is temperate maritime with winter and summer mean temperatures of 0.0 °C and 15.6 °C, respectively, and an average annual precipitation of 712 mm with regional differences of up to 300 mm (Danish Meteorological Institute, 2011; Statistics Denmark, 2010).

Cultural development of the originally mostly forested Danish landscape has been at least 6000 years in the making (Fritzbøger, 1994). Forest cover now only accounts for approximately 13% (Johannsen et al., 2009), while agriculture occupies 62% of the total land area (Statistics Denmark, 2009), one of the highest percentages in Europe (Eurostats, 2014). Denmark also has a high population density of 128.4 pers/km^2 (Statistics Denmark, 2010), with the strongest urban development in the metropolitan area of Copenhagen, on the east coast of Central Jutland and on Funen (Organisation for Economic Co-operation and Development, 2010).

Raudsepp-Hearne et al. (2010) used Canadian municipality boundaries as their sampling units. As Danish municipalities are much larger than those in the Canadian study, and a uniform grid is better suited for spatial analyses because of consistency in area,