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A multi-criteria, ecosystem-service value method used to assess catchment suitability for potential wetland reconstruction in Denmark

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ABSTRACT

Wetlands provide a range of ecosystem services such as drought resistance, flood resistance, nutrient deposition, biodiversity, etc. This study presents a new multi-criteria, ecosystems service value-driven method to drive the optimal placement of restored wetlands in terms of maximizing selected ecosystem services which a wetland can provide or affect. We aim to answer two questions: 1) which of the ecosystem services indicators defines the placement of wetlands today? 2) Based on the ecosystem services indicator assessment, what are the recommendations for future selection of catchments for potential wetland reconstruction (i.e. restoration)?

Five key ecosystem services indicators produced or affected by wetlands in Denmark were mapped (recreational potential, biodiversity, nitrogen mitigation potential, inverse land rent, and flash-flood risk). These services were compared to current placements of wetlands. Furthermore, scenario testing and hotspot analysis were combined to provide future recommendations for optimal placements of wetlands. The scenarios investigated were *Climate Adaptation and Protection of Aquatic Environment, Land-Based Economy,* and *Rich Nature*. Based on these scenarios, the most suitable areas for wetland reconstruction were mapped, taking both the scenarios and attached weightings of ecosystem services indicators into account.

According to statistical results current reconstructed wetlands are situated in catchments with lower biodiversity, higher nitrogen mitigation potential, higher land rent (i.e. agricultural intensive areas), and to some extent higher flash flood risk compared to the median of catchments with wetlands. Hence, recreation potential, high biodiversity, and low land rent has not been prioritized. 35 out of the 3023 catchments investigated were identified with an especially high suitability when optimizing all scenarios. This coincides with a high suitability around peri-urban and urban areas and near natural areas, hence capturing both supply and demand services. Of the 35 identified catchments with potentially high suitability, only 2 actually hold a presently reconstructed wetland. This indicates a prior placement with almost no consideration of maximizing ecosystem services benefits.

We recommend a systematic approach, such as the ecosystem service value-driven method demonstrated in the present case study, to target more services and improve the overall benefit from wetlands. This approach seeks to inform decision makers of synergies in the landscape, which is likely to transcend future policy implementations.

1. Introduction

Ecosystem services are the flow of natural capital to society, such as wood, fiber, food, nutrient cycling, and drinking water (MEA, 2005). Hence, wherever humans live, complex socio-ecological interactions are formed with the surrounding ecologic landscape, affecting and directing the flow of ecosystem services. These interactions can differ between regions and societies depending on local

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characteristics (MEA, 2005; Costanza et al., 2014). The value of wetland ecosystem services are among the highest of any ecosystem assessed (MEA, 2005; Russi et al., 2013), and wetlands have played a long and important role throughout history to secure human well-being (MEA, 2005; Russi et al., 2013), as well as the social and cultural evolution of humankind (Barbier, 2011; Maltby and Acreman, 2011). Therefore, wetlands might serve as a considerable part of the solution to some of the current and future global-scale problems, e.g. in relation to biodiversity loss, climate change effects, and nutrient displacement (Harrington et al., 2011; Steffen et al., 2015).

Wetlands both store excess water and function as a drought resistance as they delay the discharge of water (Barbier et al., 1997). Furthermore, they clean the water and promote deposition of environmentally damaging substances, excessive amounts of nutrients, and carbon (Kayranli et al., 2010; Adhikari et al., 2011). Studies have suggested that especially the increase in droughts, due to global climate changes, is threatening the persistence of wetland ecosystems in many areas around the globe (Okruszko et al., 2011; Pachauri et al., 2014). For Central Europe, a possible 26–46% loss of these ecosystems because of water scarcity and hydrological changes has been estimated (Okruszko et al., 2011). In northern Europe, however, it is projected that there will be more precipitation in the future and thus more surface water and extreme rainfall events (Frei et al., 2006; Brander et al., 2012), potentially increasing the abundance of wetlands.

The year 2015 was the original year set by the Water Framework Directive (WFD) (Directive 2000/60/EC) where all the surface and ground water in every European Union Member State, including Denmark, were to reach 'good' conditions. This policy represents a large scale attempt to manage water resources across political borders and change the way natural resources are managed (Chave, 2001). The WFD was implemented in 2000 to improve the water quality in designated water bodies across the member states. This included groundwater (enhancing the chemical and quantity status) as well as surface water (enhancing the ecological status and the chemical/nutrient status). Subsequent legislation in Denmark is based on implementing the objectives of the WFD (Dalgaard et al., 2014). These policies are simultaneously directed at improving the water environment among others by using restoration or reconstruction of water ways as a method to reduce nitrate pollution in surface waters (Dalgaard et al., 2014).

In Denmark, wetlands have been drained for centuries to increase the area of agricultural land, leading to a 70% reduction in natural wetland areas as compared to the situation in 1800 C.E. (Larsson, 2004). This has severely lowered wetlands' ecosystem service potential. With future climate changes more extreme weather conditions are expected in Denmark (e.g. more intensive rainfall and storms), potentially increasing material damages to both public and private holdings (Grøndahl et al., 2014). Furthermore, Denmark has set a target to reduce the pressure of active N pollution from human activities, stop the loss of biodiversity and the general decline in nature quality, connectivity, and heterogeneity (Agger et al., 2012). Until now, most policies on the restoration of wetlands have been directed by the WFD to mitigate nitrogen and phosphorus output (Natur og Landbrugskommisionen, 2013). Consequently, the current selection of potential sites for reconstructing (i.e. restoring) wetlands in Denmark has primarily been driven by the leaching of especially nitrate, and the nutrient loss reduction cost-effectiveness of wetland projects and this most likely dominate the placement of these wetlands (Jacobsen, 2012; Danish Ministry of Food, agriculture and Fisheries, 2015). Hence, the placement of wetlands has probably not taken other potential wetland ecosystem services into account. The potential of reconstructed wetlands to increase biodiversity and offer flood protection and recreational value etc. has therefore probably been undervalued. Therefore, there is a need to increase the awareness and improve methods to secure the high potential of wetlands. This includes long term perspectives, such as mitigation of climate change projections of increased flash floods and biodiversity protection, as well as the possibility of recreational values in the newly reconstructed wetlands.

With management of natural resources follows an inevitable trade-off between various types of land use (Turner et al., 2015). A repeatedly reported trade-off occurs between agriculture and natural areas (Raudsepp-Hearne et al., 2010; Bai et al., 2011; Dick et al., 2014; Turner et al., 2014). Earlier research has shown that the present distributions of ecosystem services in Denmark are non-random and appear in distinct groups (clusters) in the Danish landscape (Turner et al., 2014). These are driven by policy and land-use gradients between agriculture- and forest-dominated landscapes, in a distinct east-west gradient broadly reflecting increasing demands for cultural and recreational services in the urbanized and densely populated eastern parts, and socio-biophysical drivers of agriculture and natural wetlands' regulating services in the west (Turner et al., 2014).

Sustainable management of trade-offs becomes more key as the value of wetlands increase with human population and anthropogenic pressures on the landscape (Ghermandi et al., 2010). To obtain long-term sustainable land management, policy must encompass the economic, social, and environmental aspects that reflect the conditions in a local geographical context (Cowling et al., 2008). Therefore, it is not possible to generate a single grand scheme for selecting optimal sites for reconstructing wetlands (Harrington et al., 2011), as the optimal situation depends of the weighting of these criteria. Consequently, it is of high priority to develop methods to ensure sustainable management while embracing most interests. Here, we combine two methods to assess catchment suitability for wetland reconstruction; future scenarios and hotspot analysis:

- Scenario testing is a common used approach which typically describes the outcome of various policy scenarios, both within the field of nature conservation (Melbourne-Thomas et al., 2011; Okruszko et al., 2011) and in socio-ecology (Willemen et al., 2010; Swetnam et al., 2011; Jarchow et al., 2012; Whitfield and Reed, 2012; Bateman et al., 2013).
- Hotspot analyses, on the other hand, is often used to identify hotspots of e.g. threatened species (Grenyer et al., 2006), appropriate areas for targeted conservation (Naidoo et al., 2008; Greve et al., 2013), or to detect areas providing most ecosystem services (Egoh et al., 2008; Raymond et al., 2009; Bai et al., 2011; Fisher et al., 2011).

Within the field of socio-ecology, both future scenarios and hotspot analyses have been widely used to describe changes in ecosystem services in for instance management dynamics, but the combination of the two has to our knowledge not been used previously.

1.1. Aim of study

This paper will analyze the potential of using ecosystem services indicators, defined as indicators of ecosystem services which a wetland can provide or affect, to locate the related, most suitable catchments for reconstructing wetlands in the Danish landscape. A suitable area is hypothesized to be characterized by:1) low recreation potential, 2) high biodiversity, 3) high nitrogen mitigation potential, 4) low land rent, and 5) high risk of flooding during extreme weather events. We hypothesize that until now the placement of reconstructed wetlands is spatially determined by the funding from policies of nitrogen mitigation in agriculture, and