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Trade-off analysis of ecosystem service provision in nature networks

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ABSTRACT

We propose a spatial multi-criteria decision analysis approach as a value-focused decision support tool for evaluating land use change decisions affecting multiple ecosystem services. In an empirical case study concerned with creating a robust and interconnected network of natural areas in a Danish municipality, we first conduct a biophysical and economic baseline mapping of ecosystem services. We then construct a spatially explicit multi-criteria decision analysis model which is utilized to identify candidate areas for inclusion in the network. We define a base scenario for future land use in the area, where all criteria have equal weight, and assess the outcome in terms of welfare economic benefits of ecosystem services and opportunity cost of reducing forest and agricultural production. As weights in multi-criteria analysis is innately a subjective task, we conduct a sensitivity analysis using four corner solution scenarios. The analyses illustrate the possible range of impacts and highlight the specific trade-offs between different ecosystem services. We argue that a multi-criteria decision analysis approach will help inform decision makers in a structured and informative way when considering future land use changes.

1. Introduction

The EU Biodiversity Strategy 2020 addresses maintenance and improvement of ecosystems and their services, calling for significantly increased focus and frequent evaluations of these from a biophysical point of view. Even more ambitious is the goal of integrating economic values of ecosystem services into national and EU accounting and reporting systems by 2020 (Maes et al., 2013). Preliminary mapping and evaluation have already been conducted at European level, and it is clear that large data deficiencies prevent full economic evaluation (Bateman et al., 2011). However, a number of assessments are useful references such as the Millennium Ecosystems Assessment (World Resources Institute, 2005), The Economics of Ecosystems and Biodiversity (Sukhdev et al., 2010), and the UK National Ecosystem Assessment (Watson et al., 2011). Valuation studies are abundant but still context dependent with respect to assigning monetary values to ecosystem services. Thus complete and comprehensive cost-benefit analyses for land use changes remains challenging.

In Denmark, the Danish Nature and Agriculture Commission (NAC, 2013) published a number of recommendations on how the structural, economic and environmental challenges of the current land use in Denmark can be addressed. The future implementation of NAC's recommendations may include the establishment of a green nature network is to create a more robust and interconnected natural environment for improved biodiversity protection.

Environmental decision making in such cases is in general challenged by unclear and sometimes internally incompatible objectives. Furthermore, knowledge about the suite of potential alternatives and their outcomes is often incomplete among decision makers, in particular when the outcome depends on spatial and temporal dynamics. Multi-criteria decision analysis and structured decision making may assist in evaluating what land areas to designate for nature protection when faced with such multiple objectives (Gregory et al., 2012). This study presents an application of a multi-criteria approach to prioritize future land use in a robust and coherent green biodiversity network based on quantitative performance measures of ecosystem services within the Haderslev Municipality in Denmark. It illustrates the aspects of biophysical and welfare economic trade-offs between ecosystem services and shows the applicability of spatial multicriteria evaluation tools for the mapping and assessing of ecosystem services for decision making.

2. Case study area

All municipalities in Denmark with the assistance of the Danish Nature Agency are required to appoint areas suitable to become part of a national nature network (Ministry of Environment, 2014). Haderslev Municipality in the South Eastern part of the mainland Jutland was chosen as an illustrative case area, as it contains a wide variety of ecosystems in agricultural land and forests as well as coastline and

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Fig. 1. Location of the case area Haderslev Municipality in Denmark.

cities. Out of a total surface area of 81,370 ha, agriculture accounts for 56,951 ha or approx. 70% of the Municipality's area, higher than the country average of about 62%. Forests account for 9407 ha or 11.6%, somewhat below the country average (University of Twente, 2013). The remaining areas are either open nature, for example heathland, especially in the western part, and towns and roads (Fig. 1).

In this paper, the effects of three conservation measures are analyzed:

1) Afforestation of agricultural land and conversion of managed forests into un-managed forest set aside for biodiversity protection
2) Conversion of agricultural land into extensive grassland

The conservation actions in forest include an immediate stop of forestry intervention and drainage in broadleaved forests, allowing for conversion of commercial production forests into unmanaged forests with natural hydrology. Unmanaged forests will secure continuity of forest cover and gradually increase the amount of dead wood, as well as variation and dynamics with respect to tree species, age structure and density. Reduced forest interventions will benefit a range of species including saproxylic insects and hole-dwelling birds as well as epiphytes and fungi (Friedel et al., 2006; Ódor et al., 2006; Brunet et al., 2010; Müller 2010; Müller et al., 2013; Lassauce et al., 2011). The conversion of agricultural land into grassland includes: (1) Maintenance of existing natural areas, (2) increased area (expanding the current natural areas), and (3) reduction of nutrient pollution. Maintenance includes grazing, harvest of hay and/or clearing of scrub, to prevent invasion by shrubs and trees. Open natural grassland areas in Denmark are typically very fragmented, and increasing the area is believed to benefit the survival of species through increased ability to maintain viable (meta) populations (Rouget et al., 2006). These two measures are selected to represent a high focus on protecting nature values in both open country and forests and can be considered two extreme measures.

3. Methodological approach

Making decisions about alternative actions affecting the environment requires not only careful thinking about the potential outcomes, but also conceptual thinking about whether the decision process should be alternative-focused or value-focused (Keeney, 1996). The alternative-focused approach begins with development of a limited set of alternatives, followed by the specification of values and criteria and then concludes with evaluation and recommendation of one alternative among those selected for evaluation. The risk in this approach is that the decision maker does not map the entire relevant set of alternatives and criteria. Additionally, the analyst and/or decision maker may be biased by beliefs, motivation, and prior experience, thus being in danger of overlooking less obvious alternatives (Kahneman, 2011). Oppositely, value-focused thinking initiates the decision process by mapping the values and objectives prior to considering any alternatives and the use a structured procedure for generating alternatives. This process has in recent years in environmental planning become known as structured environmental decision making (Gregory and Long, 2009; Gregory et al., 2012).

The steps in structured decision making should at least consider what objectives and performance measures will be used to identify and evaluate the alternatives, the expected consequences of these actions or strategies, uncertainties and key trade-offs, implementation and learning (Gregory et al., 2012). Decision problems where alternatives need to be developed and eventually evaluated are suitable for a value-focused approach. This study applies a value-focused structured decision making approach in the form of a spatial multi-criteria decision analysis model.

3.1. Spatial multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) is a widely used method within the frame of natural resource management (Mendoza and Martins, 2006). One obvious advantage of the method is its structured and rational approach to comprehensively deal with multi-functionality and multiple stakeholders. The MCDA further has a great potential as a decision and communication platform facilitating the handling of factors not presented in similar units. Where cost-benefit analysis embeds the challenge of converting all inputs and outputs into a single currency, the MCDA includes a similar, inherent problem of establishing precise weights among criteria (Bogetoft and Pruzan, 1997).

The MCDA used in this paper follows the general approach of finding a decision which maximizes the objective function given a feasible set of alternatives (Bogetoft and Pruzan, 1997). An objective function $v(x)$ is maximized with respect to each of the different alternatives (x) within the set of feasible alternatives (X):

$$\begin{aligned} &\text{Max } v(x) \\ &\quad \text{s.t.} \\ &\quad x \in X \end{aligned} \tag{1}$$

In dealing with land use change it is beneficial to apply a spatial GIS-based model (Mendoza and Martins, 2006). The spatial MCDA model allows for area specific characteristics and requires data on criterion values for every geographical location in its feasible alternatives. The analysis then relies on the inputs in the form of geographically positioned data, the decision maker's preferences for the inputs and their relative importance, i.e. the weights, and, finally, functions for how the inputs are to be evaluated, also referred to as score functions. These functions ensure that all data are standardized into one-dimensional values. If the spatial location of the relevant criteria is in place, the spatial MCDA model can assist in making better solutions that would otherwise be difficult to identify due to the