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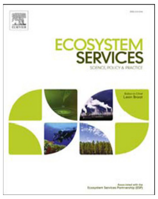

Ecosystem services mapping for detection of bundles, synergies and trade-offs: Examples from two Norwegian municipalities

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ABSTRACT

The main objective of this work was to analyse how increased harvesting for bioenergy production might affect other Ecosystem Services (ES) in two Norwegian municipalities (Ringsaker and Voss). The aim was to identify locations where synergies or conflicts between ES could be expected. The spatial distribution of eight different ES (3 provision, 3 regulation and 2 cultural services) was modelled using information provided by land use spatial databases and additional data sources. Model parameters were set by integrating existing research and expert knowledge. Maps showing the level of provision of ES were analysed using a moving window to analyse scale dependence in the spatial distribution of ES provision. Map algebra was then used to identify areas providing multiple ES, thus defining the most important areas on which to focus the management of both synergies and trade-offs. Finally, specific 'binary bundles' maps, where bioenergy provision was compared with each of the other ES, were developed. The methodology proved its utility to assess the compatibility of bioenergy uses with other services. This straightforward approach is readily replicable in other regions and can be used as a decision support tool for planning and designing provision areas, and to ensure sustainable forest management approaches.

1. Introduction

Mapping methodologies have been addressed as one of the most important elements in the application of Ecosystem Service (ES) perspectives (Martínez-Harms and Balvanera, 2012; Maes et al., 2016). Mapping involves spatially explicit inventory and analysis and is a necessary starting point for any research aiming to improve understanding of ES, as well as being essential to enable practical applications of the concepts. The methodologies developed to date differ depending on their specific objectives (e.g. Nelson et al., 2009; Burkhard et al., 2012, 2014; Bagstad et al., 2013a; Bastian et al., 2013; Crossman et al., 2013), and also vary considerably in their degree of complexity (European Commission, 2014; Grêt-Regamey et al., 2015; Maes et al., 2016). Thus, analysis of how ES perspectives can be integrated into planning and management schemes has revealed specific needs regarding ES mapping and analysis (Maes et al., 2012).

Specifically, in recent years interest on how different ES relate to each other has increased (Lee and Lautenbach, 2016). It has been recognised that management strategies focused on maximising the production of one ES may result in a decrease in an ecosystem's capacity to provide other ES (Bennett et al., 2009; Raudsepp-Hearne et al., 2010). This recognition has led to attempts to map ecosystem bundles (i.e. consistent associations in time and/or space between multiple services; Raudsepp-Hearne et al., 2010), based on the identification of ES relationships, trade-offs and synergies (Bennett et al., 2009; Raudsepp-Hearne et al., 2010; Howe et al., 2014; Lee and Lautenbach, 2016). Identification and mapping of such ES bundles are also important as a way of communicating with local stakeholders on how ecosystems and ES interact (Crouzat et al., 2015), as availability of spatial information to be further processed and displayed in different formats is essential in the communication process (Frank et al., 2012; Klein et al., 2015; Wissen Hayek et al., 2016).

An important ES related to forest ecosystems and their management is the provision of raw materials for bioenergy production (Maes et al., 2011; Pelkonen et al., 2014). While impacts and trade-offs related to forest bioenergy have been recognised (Lattimore et al., 2009; Bouget et al., 2012; Schulze et al., 2012),

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important opportunities to promote sustainable development in rural areas are linked to the potential use of renewable energy (OECD, 2012), especially at a local or community level (Alavalapati et al., 2009; Seyfang et al., 2013; Jenssen et al., 2014;). More and more studies are focusing on the potential of renewal renewable energies at different scales (Frank et al., 2015), involving integrated assessment approaches for the sustainable use of biomass at regional and local levels (Fürst et al., 2013). In this sense, an important issue to be considered is scale.

The evaluation of the scale at which the ES is provided is important for the detection of mismatches in supply, management, and demand or consumption (Raudsepp-Hearne and Peterson, 2016). This is due to the influence of scale on the relationship between provision and demand of ecosystem services (Hein et al., 2006; Palomo et al., 2013; Serna-Chávez et al., 2014). When the ES is to be consumed at local scales, it is important to define whether or at which level the supply of a given service is directly available (e.g., if the availability depends on a certain distance, or if the amount or intensity of provision varies across space). The appropriate scale of provision could then be identified as the spatial domain or extension at which the potential supply of the ES is warranted in relation to demand. In this sense, multiscale approaches based on landscape pattern analysis and spatial statistics (Díaz-Varela et al., 2009b; Roces-Díaz et al., 2014, 2015) can be useful to compare how a given ES would be potentially supplied at different scales, depending on the spatial pattern of the level of provision.

The work presented here sets a novel framework for the integration of ES perspectives in planning sustainable forest harvesting for bioenergy, including the spatial inventory of ES potential supply, synergies and trade-offs. The approach starts with GIS-based multi-criteria analysis of spatially-explicit data to produce ES provision maps. Then, moving-window techniques were used to assess how the spatial distribution of provision changed with the scale of analysis. Finally, bundles and trade-offs were identified. The resulting maps provide a foundation for public participation processes and management recommendations.

2. Methods

2.1. Study areas

The ES analysis was developed for the Norwegian municipalities (kommune) of Ringsaker (61°01′27″N 10°48′07″E), in Hedmark County, in SE Norway, and Voss (60°42′09″N 06°25′23″E), in Hordaland county, SW Norway (See Fig. 1). The municipalities were chosen as examples of rural areas with abundant farm-owned natural resources that could be suitable for the development of local bioenergy initiatives.

Ringsaker has a population of 33,597 inhabitants (SSB, 2016), and spans an area of 1279 km^2. Altitude ranges from approximately 120 to 1000 m. Climate is continental with cold winters (average February temperature: −8 °C) and mild summers (average July: 15 °C). Average annual precipitation is 590 mm (Hjeljord et al., 2014). Forests are boreal and coniferous, the dominant species being *Picea abies* L. and *Pinus sylvestris* L., with occasional mixtures of broadleaved species, especially *Betula* sp. Forests are subject to intensive commercial forestry (Hjeljord et al., 2014). Agriculture occurs mainly in the SW part of the municipality, and includes cereal and fodder crops, as well as potato and vegetables. There is also diverse livestock production in the area (SSB, 2012). Tourism related to water sports, trout fishing and other outdoor activities is also an important economic activity.

Voss has a population of 14,425 inhabitants (SSB, 2016), and spans 1808 km^2. Altitude ranges from sea level to approximately 1,600 m. The climate is semi-oceanic, with average air temperature ranging from −5 °C in January to 16 °C in July. Average annual precipitation is 1200 mm (Hindar and e Jonsson, 1982). Boreal forests occupy large areas, dominated by *Picea abies* and *Pinus sylvestris*. Smaller patches of deciduous forest are also present, dominated by *Betula* sp. The forests are managed less intensively than in Ringsaker, mainly due to the difficulties imposed by a more complicated relief, climate and infrastructure (Rødland, 2009). Agricultural land comprises mainly pastures and meadows, with a very small area of cereals or vegetables (SSB, 2012). Tourism is of high importance, mainly related to water and winter sports and other outdoor activities.

2.2. Ecosystem services

Of the various ES classification systems available (see e.g. de Groot et al., 2002; MA, 2005; Wallace, 2007; Constanza, 2008; Haines-Young and Potschin, 2009), we adopted the Common International Classification of Ecosystem Services (CICES) Ver. 4.3 from January 2013 (CICES, 2016). CICES provided a framework for the nomenclature and selection of a set of ES that could be assessed based on the available data. The selection represented a diverse sample of ES that could affect, or be affected by, increased harvesting of forest resources for bioenergy production. CICES classifies the ES hierarchically in “Sections”, “Divisions”, “Groups”, “Classes” and “Class types”. Table 1 defines the set of ES analysed in this work according to the three upper levels of the CICES hierarchy.

Specific ecosystem class types were considered in order to link ecosystems and their services, and thus obtain more precise and clear results (see Table 1, and Section 2.4).

2.3. Digital cartography

The Norwegian high resolution land resource database AR5 (Bjørdal and Bjørkelo, 2006; NIBIO, 2015) was used as input for Land Use/Land Cover (LULC). This was used as a reference for the spatial arrangement of the ecosystems in the study areas, as well as for their characteristics regarding the capacity for provision of ES. AR5 is a categorical digital map, available in shape file format, that includes: a) land use types; b) tree species; c) site index (a term used in forestry to describe the potential for forest trees to grow at a particular location); and d) ground conditions (soil depth, presence of peat, bare rock or boulders). Details of the classification schemes and legends are described in Bjørdal and Bjørkelo (2006). Digital Elevation Model DTED 10 Norge (Kartverket, 2016), with 10 × 10 m resolution, was used to derive topographical attributes.

2.4. Analysis and representation of ES provision using multicriteria methodologies

2.4.1. Approach

We performed a GIS based multicriteria decision analysis (Eastman et al., 1995; Malczewski, 2006; Malczewski and Rinner, 2015) for the generation of Ecosystem Service Provision Units (ESPU). Map algebra was performed following a weighted linear combination (modified from Eastman et al., 1995):

$$F_{ESi} = \sum_{i=1}^{n} V_i * W_i$$

Where F_{ESi} is the quantitative value of the land’s capability to provide or supply the ES. V_i is the value for each *i*th criterion (e.g. land type, tree species, slope…) considered for the analysis of a given ES, and classified in values ranging from 1 to 5. W_i is the relative weight for each criterion according to how important it was considered to be compared with the other criteria ($\Sigma W_i = 1$).