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Comparative study on biophysical ecosystem service mapping methods—a test case of carbon stocks in Finnish Forest Lapland

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ABSTRACT

Mapping of ecosystem services in biophysical environment helps distinguishing the nature's benefits in our surroundings. Ecosystem services also enable assessing the level of sustainability of the use of the environment. Various methods are being used for mapping them and methods: vary from expert evaluations to complex modelling. All methods: are related with uncertainties and affect to their applicability for different purposes. In this study, two different level biophysical mapping based datasets were tested; 1) data combination of biophysical polygon GIS data (SutiGIS) and statistics, and 2) modelled data of National Forest Inventory were evaluated to compare the differences between the methods: for carbon storages. Our results show that there are differences between results that have been produced in different levels of complexity. However, we also discovered that simpler datasets can also help detecting the shortcomings that may occur in modelling. We discuss also the potential applications of the used datasets in terms of providing information on biodiversity in ES assessments.

1. Introduction

Nature's role in human well-being is assessed with the concept of ecosystem services (ESs) to clarify the human dependency of functioning ecosystems (MEA, 2005; Vihervaara et al., 2010a). Monitoring the state and trends of ecosystem service delivery has required development of numerical ecosystem service indicators to assess the magnitude of changes in the biophysical environment and ESs (e.g. Kandziora et al., 2013; Mononen et al., 2016; Albert et al., 2016; Maes et al., 2016). The evaluation of the sustainability of land use can be based e.g. on structural and functional indicators describing the ecosystem integrity (Müller, 2005). Both natural and anthropogenic changes in land use and alterations in land cover affect the landscapes' ability to provide ESs (e.g. DeFries et al., 2004; Carpenter et al., 2009). Thus, ecologically sustainable use of ecosystems and their services is required to maintain the functioning of the ecosystems. In order to detect the spatial variation in ES delivery across space is essential to distinguish the varying environmental and socio-ecological conditions (Wiggering et al., 2006; Syrbe et al., 2007). For the purpose, various mapping methods are being used to access to spatial information on ESs (Maes et al., 2012).

Mapping of ecosystem services is important to evaluate the distribution of ES supply at different scales and how they meet with their demand since resources are often unevenly distributed in the landscape and the demand for them is elsewhere (Fisher et al., 2009; Bastian et al., 2012). This is particularly the case for provisioning services that can be extracted from their original site. For regulating services the benefits are experienced locally, regionally and even globally. For the cultural services the benefit is acquired by physically visiting the desired location or by getting inspired by images or other material. Spatially explicit mapping is needed in order to monitor the impact of changes in the environment (Nelson et al., 2009) and targeting of conservation (Daily and Matson, 2008) and therefore support sustainable decision-making for targeting of investments and policies concerning the natural resources (McKenzie et al., 2011). Spatially explicit mapping will also allow assessments of trade-off between different ecosystem services and

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biodiversity (McKenzie et al., 2011; Maes et al., 2012). Mapping is important also for governance of ecosystem services, for instance, through sustainable land use planning. The variety of methods are being categorized under so called "Tiers" (1–3) based on their levels of detail and complexity that would in the end help in deciding the methods for future ES studies (Maes et al., 2014; Esmeralda project: esmeralda-project.eu). The biophysical ES mapping methods link the biophysical environment at various levels from the use of rough land cover maps to use of species traits data or even more sophisticated ecosystem process based models including e.g. climate models (Lavorel et al., 2014). Spatial proxy models are commonly used for ES mapping and they allow use of different level of complexity (Maes et al., 2012). All methods involve uncertainties. In this study, we compare how two methods can give different results by mapping 'carbon stocks', that is the indicator for the ecosystem service 'climate regulation', in Finnish Lapland.

Climate regulation is a regulating service that is of global importance. Carbon stocks are many times considered to define the structure in land cover that participates in the ecosystem process to deliver the ecosystem service (Kandziora et al., 2013; Mononen et al., 2016). Forest ecosystems are typically the target ecosystem (biomass and soils) when calculating the carbon stocks but mire, freshwater and marine ecosystems store carbon as well. Carbon stocks in forests are often assessed through measured biomass. Vegetation affects to soil and soil affects to vegetation's capacity to sequester carbon. Lau and Lennon (2011) show that below-ground microbial communities have influence on plant diversity, plant productivity, and composition of the plant community, which exemplifies the important relationship between biodiversity, ecosystem functions and ecosystem services. Site characteristics and plant composition define how much carbon can be stored in the above-ground biomass. In boreal forests of Northern Fennoscandia, there are only few dominating tree species; spruce (*Picea abies* (L.) Karst.), pine (*Pinus sylvestris* L.), and birch (*Betula* spp.). Differences in carbon levels with different tree species have been measured (e.g. Repola et al., 2007; Repola, 2008, 2009). Also the number of tree species in the same forest patch has been studied to increase biomass productivity (Gamfeldt et al., 2013). Main limiting factors of Net Primary Production (NPP) are cooler climate and shorter growing season (Goulden et al., 1998; Lindroth et al., 1998) but also factors such as soil moisture and site productivity affect to the formation of biomass. The heterogeneity within-patch and landscape and landscape fragmentation has effect on forest carbon cycling and carbon stocks (Robinson et al., 2009). In boreal forests, soil carbon storage is greater compared to tropical forests (e.g. Pan et al., 2011) and even over the boreal zone the density of carbon stocks vary greatly (Liski, 1995). In global scale boreal forest soils are important carbon pools and carbon sinks (Batjes 1996; Juutinen et al., 2013; Kasischke and Stocks, 2000). Soil carbon accumulation is affected by the same elements as in above-ground biomass, i.e. land cover, climatic factors and soil type. Disturbances such as forest fires, windfalls and insect outbreaks can temporarily reduce the rate of carbon accumulation (Deluca and Boisvenue, 2012).

In this study, the carbon stocks of Northern boreal forests are assessed through above-ground biomass (in this case also including roots and stumps) by using two methods; 1) Combining National Forest Inventory statistics with corresponding land cover classes from SutiGIS (Metsähallitus) and 2) Multi-Source National Forest Inventory (MS-NFI) data that is modelled across Finland. Then the differences between the two methods are evaluated and their usability in ES mapping is discussed. The results are also evaluated from the perspective of protection by comparing carbon storage densities in protected and non-protected areas. The applicability of biotope classification in SutiGIS data is evaluated based on the results gained from the first method.

2. Material and methods

2.1. Study area

The study area is located in the Northern boreal forest zone in northern Finland (between ca. 68–69°N, 26–29°E) (Fig. 1). The duration of growing season varies between 100 and 135 days per year. The temperature sum varies 600–800 °C day and the sum of precipitation is between 240 and 280 mm during the growing season (Finnish Meteorological Institute, 2016). The area is characterized by coniferous forests dominated by Scots pine (*Pinus sylvestris* L.). Spruce (*Picea abies* (L.) Karst.) forest occurs only in the southern part of the research area. Deciduous forests are birch dominated but mountain birch (*Betula pubescens* spp. *czerepanovii*) dominates near the tree line. Mixed forests of the area are a combination of these tree species. In total the study area covers 9 880 km^2.

2.1.1. Land use and land cover change in the study area

Forestry, reindeer herding and recreation are the primary land use types and livelihoods in Lapland today and all of them are actively practiced in the selected study area (Fig. 1). The area is formed from three reindeer-herding districts: Hammastunturi, Ivalo and Lappi. This area was chosen for this study because of the availability of the detailed habitat data provided by the state forestry department (Metsähallitus) (SutiGIS) and previous ES studies (Vihervaara et al., 2010a, 2012a,b). Boreal forests in Finland have undergone significant changes since the 1950's, when a shift to new land use forms took place and caused changes in the land cover. Intensive forestry increased rapidly in the post-World War 2 period. Among forestry, reindeer herding as traditional source of livelihood has also had to adapt to newer competing land use forms, such as hydropower construction, mining, and tourism infrastructure that altogether have made significant changes in the landscape. For example in the Lappi reindeer herding district, it was estimated that circa 27% of the total area has experienced major disturbances since the late 1960's (Kivinen and Kumpula, 2014). The establishment of natural protection areas has preserved the remaining old growth forest. Our study area constitutes of large protection areas, wilderness areas and sites belonging to EU's Natura 2000 network (Lindqvist and Posio, 2005). Altogether protected areas cover 3800 ha area.

2.2. Methods

The used methods for carbon storage mapping are presented in chapters 2.2.1 and 2.2.2. Their results are compared with each other by extracting the results from each other. Additionally the differences have been evaluated from the perspective from protection and biodiversity.

2.2.1. Combination of NFI statistics with detailed habitat data with GIS

Two datasets were used for this method. The detailed polygon GIS dataset (*SutiGIS*) (Metsähallitus, 2007) was supplied by Metsähallitus. SutiGIS data is compiled from aerial images (1 m resolution) which have been used to digitize general patterns. Each pattern has been given the parameters on development class, tree species dominance, land class, main site class and site fertility class for each forest patch (Fig. 2). The patches are divided into divisions according to the development class of the trees. Data is validated and corrected by field data. This data has been evaluated being suitable for assessing ecosystem services as being more refined