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Towards better mapping of forest management patterns: A global allocation approach

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ABSTRACT

Forests provide numerous ecosystem services, such as timber yields, biodiversity protection and climate change mitigation. The type of management has an effect on the provision of these services. Often the demands for these services can lead to conflict – wood harvest can negatively impact biodiversity and climate change mitigation capacity. Although forest management differences are important, spatially explicit data is lacking, in particular on a global scale. We present here a first systematic approach which integrates existing data to map forest management globally through downscaling national and subnational forest data. In our forest management classification, we distinguished between two levels of forest management, with three categories each. Level 1 comprised primary, naturally regrown and planted forests. Level 2 distinguished between different forest uses. We gathered documented locations, where these forest categories were observed, from the literature and a database on ecological diversity. We then performed multinomial logit regression and estimated the effect of 21 socio-economic and bio-physical predictor variables on the occurrence of a forest category. Model results on significance and effect direction of predictor variables were in line with findings of previous studies. Soil and environmental properties, forest conditions and accessibility are important determinants of the occurrence of forest management types. Based on the model results, likelihood maps were calculated and used to spatially allocate national extents of level 1 and level 2 forest categories. When compared to previous studies, our maps showed higher agreement than random samples. Deviations between observed and predicted plantation locations were mostly below 10 km. Our map provides an estimation of global forest management patterns, enhancing previous methodologies and making the best use of data available. Next to having multiple applications, for example within global conservation planning or climate change mitigation analyses, it visualizes the currently available data on forest management on a global level.

1. Introduction

Forests provide numerous ecosystem services, such as carbon sequestration, biodiversity conservation, water regulation, erosion control, habitat, recreation space and many more (Ninan and Inoue, 2013). Probably the most prominent is the production of wood biomass, one of the crucial resources for humankind. Our dependence and needs for a wide range of forest ecosystem services is reflected in different types of forest management. These either aim for maximizing the provision of one service (usually timber production) or compromise between several services. However, they can also result in different levels of pressures, alteration and degradation of forests. A distinction can be made between so-called "conventional" and "alternative" forest management. Conventional practices aim for an increase of timber yields and harvest efficiency, usually resulting in species-poor and even-aged forest stands (Puettmann et al., 2015). Alternative silvicultural systems are aiming for more diversity in age, species and structure (Puettmann et al., 2015).

Globally, there are different ways of how these types are implemented. For Europe, Duncker et al. (2012a) classified five different forest management approaches, ranging from passive (unmanaged forests) to intensive (short-rotation forests). The two approaches with the highest management intensity (i.e. high and intensive) thereby correspond to conventional silviculture and the once with lower management intensity, i.e. low and medium, describe alternative systems. In the tropics, selective logging is a common practice for both, conventional and alternative logging systems, since natural forests have a high variety of tree species and only some are suitable for timber

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(Chaudhary et al., 2016). Therefore, a distinction is made between conventional selective logging with heavy machinery and reduced impact logging, which includes harvest planning and practices that cause less damage (Puettmann et al., 2015).

In general, high management intensities result in high merchantable timber yields and can be beneficial for climate change mitigation (Duncker et al., 2012b). However, when large trees are harvested unsustainably, smaller trees can get damaged or destroyed, which can significantly contribute to carbon loss and forest degradation (Martin et al., 2015). High management intensity also negatively affects other ecosystem services (Duncker et al., 2012b; Pukkala, 2016), for example biodiversity. The magnitude of the effect on biodiversity varies substantially among management type, geographical location and affected taxonomic group (Chaudhary et al., 2016). Logging can result in a high age class diversity, when conducted at low historical rate or maximum age, thereby mimicking a natural disturbance regime (Colombo et al., 2012). On the other hand, logging is, besides crop farming, the biggest threat to Red List species (Maxwell et al., 2016). Wood production and trade were furthermore identified to contribute substantially to extinction risks of bird species (Nishijima et al., 2016). Moreover, the conversion of a forest to a timber plantation can have an effect on species composition and is one of the main drivers of extinction and biodiversity loss (Newbold et al., 2015).

Demands for forest ecosystem services, particularly wood, will likely increase in the future, due to demographic changes, economic growth and the encouraged use of biomass for energy production (Egnell et al., 2011; FAO, 2009, 2016). Additional pressure on forests can be expected from expanding agricultural areas to fulfill the global food demand (Lambin and Meyfroidt, 2011) and an increase of land demands for biodiversity protection and climate change mitigation (Eitelberg et al., 2016). To analyze future impacts of land use conversions, land change models are often applied, driven by human demands for food, resources and living space (Brown et al., 2013; Veldkamp and Lambin, 2001). In such models, forest is often classified based on the land cover only. The same is valid for conservation planning through the identification of priority areas, where forests are included only in terms of forest cover (Brooks et al., 2006). Habitat loss due to forest degradation or conversion to monoculture plantations is, consequently, not considered. To estimate an area's relative importance for biodiversity protection or its contribution to climate change mitigation, it is necessary to go beyond forest cover and deforestation patterns. There is a need to better consider the spatial patterns of forest management.

Several datasets exist that give information of forest management types. On a national scale, there is the Global Forest Resources Assessment (FRA), compiled by the Food and Agriculture Organization of the United Nations (FAO). It provides an insight into characteristics and functions by giving extents of different forest categories, gathered from national inventories, partially using remote sensing (MacDicken, 2015). On a spatial explicit level, some previous studies aimed to capture patterns of different forest management on national, continental or global scales (Hengeveld et al., 2012; Hurtt et al., 2011; Kraxner et al., 2017; McGrath et al., 2015; Naudts et al., 2016; Petersen et al., 2016; Verkerk et al., 2015). Three reoccurring main approaches were found in the literature: (1) an evidence-based approach, (2) reconstruction of historical wood harvest and land use and (3) direct observation through remote sensing. Although these existing efforts have resulted in different maps, they are either spatially restricted, are based on rather simplified assumptions or use a coarse thematic resolution (see SI for a more in-depth inventory).

A systematical approach of identifying global patterns of forest management is still missing. The objective of this study is therefore to improve our understanding of global forest management types. We aim to map forest classes, such as natural or planted forest and forest uses, such as for production. While these are not equal to forest management systems, they give information on where wood is produced and where forests are disturbed by humans. Moreover, we aim to study the underlying drivers behind the location of different forest classes and uses, by integrating publicly available global data and build up on the methods currently used in the literature.

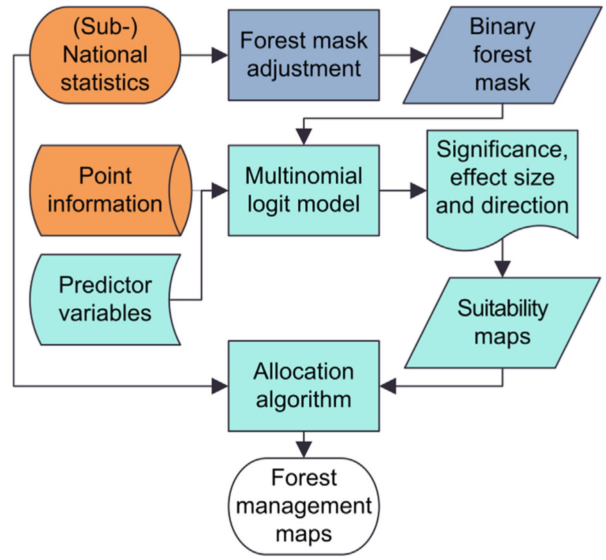

Fig. 1. Simplified flowchart of the methodology. The flowchart depictures inputs (left), process steps (middle) and interim results (right) for the creation of global forest management maps. The colors indicate which part of the method section a thorough explanation can be found - orange: *Classes and data*, dark blue: *Preparation for spatial analysis*, turquoise: *Likelihood maps and allocation*.

2. Methods

The following paragraph gives a brief overview of the methodology. Each step is then explained in more detail in the following sections. Our methodology is based on downscaling national and subnational data using empirical data to determine the likelihood of finding a forest management type at a specific location (see Fig. 1), following the method applied in previous studies (Kraxner et al., 2017; Verkerk et al., 2015). We determined the likelihood of finding a specific forest management type by estimating multinomial logit regression models. This included evaluating the effect of 21 different predictor variables. For the dependent variable, data points from the literature and a new database of case study observations on ecological diversity were used. Hypotheses on the behavior of predictors were made beforehand. By means of significance and effect of predictors, we calculated likelihood maps for the occurrence of different forest categories. Those formed the basis of spatial allocation of forest classes. Our final maps represent an estimation of two levels of global forest management patterns for 2000 at a 1 x 1 km^2 resolution, following an underlying forest cover map (see below).

2.1. Classes and data

We used national forest data from FAO's FRA, 2015 version (FAO, 2016) for the year 2000. The FRA is a data collection of the extents of different forest categories for in principal all countries and territories, but for some countries data is missing or these countries do not have any forest cover (Table S_4). An important advantage of the FRA dataset is its global coverage and given definitions. Furthermore, it is commonly used in land and global change studies, e.g. on climate change, biodiversity and remote sensing, substantially contributing to more than 150 studies (Grainger, 2008). The FRA dataset was improved with subnational statistics, thereby increasing the spatial resolution of information for the seven biggest countries, namely Australia, Brazil, Canada, China, India, Russia and the USA (see Table S_1 for data